UPPER OHIO NAVIGATION STUDY, PA FINAL FEASIBILITY REPORT AND INTEGRATED ENVIRONMENTAL IMPACT STATEMENT

COMMUNICATION

FROM

THE ASSISTANT SECRETARY OF THE ARMY, CIVIL WORKS, DEPARTMENT OF DEFENSE

TRANSMITTING

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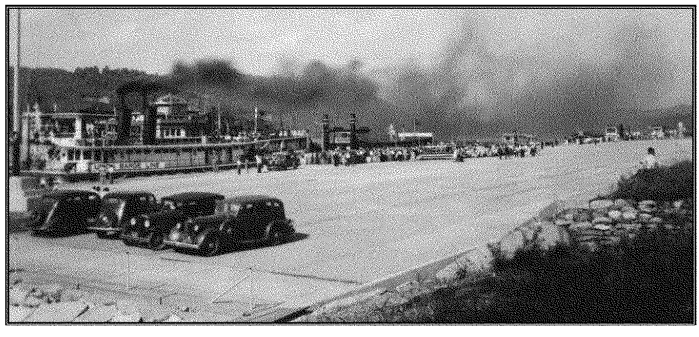

Opening celebration at Montgomery Locks and Dam - 1936

Emsworth, Dashields, and Montgomery Locks and Dams

Chapter 9
RECREATION

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9.2 DEFINITION OF RIVER-RELATED RECREATIONAL IMPACTS

River-based recreation activities on the Ohio River mainstem include, but are not limited to, recreational fishing and hunting, pleasure boating, water-skiing, and swimming. Pleasure boating includes use of privately owned or rented motorboats, personal watercraft (PWC), and non-powered watercraft (canoes, etc.) as well as sightseeing/dining and related activities aboard commercial watercraft. Additionally, the Ohio River and its riparian environs provide a setting for a broad range of 'shore oriented' activities that include hiking, biking, picnicking, camping, scenic drives, sightseeing, birdwatching, bank fishing, riverfront dining, and special events such as festivals, regattas, or fireworks displays. Both on-the-water and shore oriented recreational activities may have the potential to create crowding conditions at certain times or places that may conflict with other recreational activities or with commercial uses of the river.

Recreational activity contributes to development and/or preservation of a broad spectrum of public and privately funded recreational support features. These include

individual boat launching ramps, riverfront parks, trail and greenway corridors, marinas and moorage facilities, and floating restaurants. In addition to river oriented recreational activities, riverfront settings are also popular locations for sports stadiums, museums, concert facilities, casinos, on-shore dining-shopping-entertainment complexes, hotel and convention centers, and residential developments. Opportunities for further enhancement of recreation and tourism oriented facilities are prominent features in virtually all riverfront oriented planning among individual communities and public/private regionally focused groups along the Ohio River.

These activities are expected to increase on the Ohio River mainstem due to increased leisure time, overall improvements in river water quality, and increased access via boat ramps, marinas, river oriented parks and other developments. Recreation oriented riverfront developments may compete with or displace other uses along the river. Conversely, the process of planning and providing publicly funded or subsidized recreational facilities has the potential to contribute to long term protection of those resources (e.g., greenways, viewscapes, and public access) that in turn heighten demand for such recreational opportunities.

Potential health and safety (H&S) impacts can occur to recreational users due to the proximity of these activities to navigational uses (barge traffic) or other uses of the river. Further, potential conflicts over river use can occur between navigation, recreation, and other stakeholders. For example, increased levels of navigation could lead to pressures to reduce recreational boating in some congested areas.

9.3 OBJECTIVES AND SCOPE OF THE RECREATION STUDY

9.3.1 Objectives

This chapter provides an overview of recreational activities and trends throughout the Ohio River mainstem. Additionally, this chapter assesses the system-wide Cumulative Effects (CEs) to recreation of all likely major navigation improvements along the mainstem of the Ohio River from 2000 - 2070. Impacts that are directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and Reasonably Foreseeable Future Actions (RFFAs) by the US Army Corps of Engineers (Corps) and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFAs. These future actions include the major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, non-governmental entities, and predictions of general economic expansion and development.

The results of the Cumulative Effects Assessment (CEA) are intended to contribute to two topics of subsequent public debate: (1) whether the impacts of the RFFAs constitute acceptable outcomes for the affected resources and (2) how the proposed navigation improvements contribute to those outcomes.

9.3.2 Geographic Scope

The geographic focus for this study of Ohio River recreation includes those areas most directly impacted by operation and maintenance of the navigation system. In order to reflect influences of the navigation system in the context of broader business and economic forces, as well as to maintain consistency with the scope of other chapters (e.g., Socioeconomics, Health and Safety), counties adjacent to the Ohio River mainstem are defined as the geographic focus for impacts related to recreational activities. Where such counties are part of a Census-defined Metropolitan Statistical Area (MSA), all counties in the MSA are included in the geographic focus.

9.3.3 Time Frame

The established time frame for this assessment is 1920 to 2070. The earlier date approximates the initiation of modern Corps lock and dam construction activities on the Ohio River. The latter date approximates the end of the 60-year planning horizon encompassed by the Ohio River Main Stem System Study (ORMSS).

9.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during the Summer, 2001, in communities along the Ohio River. The meetings created opportunities for the public, state, and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. More detailed discussions of the scoping meetings are presented in Exhibits A and B of this report.

A total of 185 people attended the meetings and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted. Comments that directly or indirectly addressed recreational issues are presented in **Table 9-1.**

TABLE 9-1
Comments from Public Scoping Meetings

Direct Comments on Recreation Oriented Impacts or Issues	Total	Impact[1]
Need more public access ramps in each pool to reduce recreational crafts' usage of locks	5	R-M
Effects on fishing caused by water level fluctuations	3	-
Degradation of recreational value of river caused by increased industrialization	2	-
Interest by Ohio to promote Ohio River as a vacation destination	2	+
Increased development of scenic byways and bikeways	2	+
Under-representing of fishermen in ORMSS scoping process	1	Q
Increase in barge loading/unloading facilities limiting fishing access from shore	1	-
Danger to recreational users of submerged trees toppled by bank erosion	1	-

Direct Comments on Recreation Oriented Impacts or Issues	Total	Impact[1]
Need for examination of those licensed to operate recreational craft	1	R-M
Suggestion of greater use of levees for passive recreation	1	R-M
Effects on recreation and heritage sites in Illinois, including Tower Rock Recreation Area	1	-
Include recreational facilities as design components of L/D revitalization & construction projects	1	R-M
Need for long-term plan for replacement & maintenance of existing recreational launch ramps	1	R-M
Need more access ramps in each pool for emergency response and boating safety officials	1	R-M
Other Comments With Implications for Recreation	**Total**	**Impact**
Health and safety concerns related to increased traffic and development	3	-
Eligibility of locks for classification as historic structures	1	+
Effects on recreation and quality of life of raising Montgomery pool level	1	-

[1]Impact codes:
"+, -, +/-" Comments that suggest positive, negative or mixed impacts to recreation activities or opportunities.
"R-M, R-S" Comments recommending an action for management of river resources (M) or as a topic in the CEA study (S).
"Q" General questions.

9.5 INDICATORS OF SUSTAINABILITY

Three principal factors that contribute to the sustainability of recreational activities in a local or regional setting are opportunity, availability, and experience. Any general class of recreational activity (e.g., river oriented boating) can be interpreted as an optional use of leisure time. Opportunity to engage in such activity derives from the general socioeconomic prosperity of the population living in the study area. Accessibility refers to the general ease of access to the resource. Experience refers to the likelihood that people will continue to engage in a particular activity.

Socioeconomic trends that contribute to recreational opportunity within a given population include employment and income statistics that are routinely collected by the U.S. Bureau of the Census. A population with better than average employment and income has more opportunity for recreational activity than a population that is less affluent. Over time, population growth in concert with continued growth of economic prosperity will contribute to expanding opportunities for recreational activity. Socioeconomic factors are addressed in Chapter 11 of this report.

Accessibility refers generally to ease of access to a given recreational resource. Individuals living close to the Ohio River have easier access than individuals living an hour's travel time away. The presence of boat launch ramps, community parks, or public access to shoreline fishing sites provides improved access in comparison to areas without such facilities. The type of facility provided may also differentially benefit certain groups (e.g., boat ramps likely provide little value to hiking/biking interests). This chapter addresses past to present trends of boat ramps, marinas, and other recreation facilities mapped on Corps' Navigation Charts. Other types of access facilities and future needs/consumer demands were assessed through interviews with selected stakeholders.

Experiences gained from participation in a recreational activity will directly influence future recreational choices. Not only are individuals more likely to repeat pleasurable recreational experiences, they are likely to encourage others through word-of-mouth. The collective activity and experiences of a given population can provide a good indicator of future activity and may be able to shed light on how the population would respond to changes in the recreational resource.

9.6 LAWS, REGULATIONS, ORDINANCES AND PROGRAMS

9.6.1 Agency Guidelines

Chapter 3 of the Planning Guidance Notebook (PGN) of the Corps of Engineers (ER1105-2-100; published on April 22, 2000) contains some information related to river-based recreation. The following two items are especially pertinent:

- Statement – The U.S. Army Corps of Engineers is one of the nation's largest providers of outdoor recreation opportunities. Although known primarily for the opportunities managed at its lake projects, the Corps also participates in the planning, design and construction of recreation facilities at a wide variety of other types of water resource projects.

- Policy – Lakes, or reservoirs, are impoundments created behind dams, or behind navigation locks and dams, if lands not subject to navigation servitude are needed for water storage. Recreation policies applicable to lakes are not applicable to dry dams, that is, those dams not providing permanently impounded water. The Federal government may participate in basic recreation facilities on project lands or separable recreation lands if a non-Federal sponsor will participate and cost share. Economically justified recreation facilities are cost shared 50 percent Federal and 50 percent non-Federal. The same conditions apply to separable lands acquired for future recreation development.

9.6.2 Federal Laws and Programs

The Corps' role in the development and support of recreational opportunities along the Ohio River is addressed through a number of laws and related authorizations. In addition to rulemaking that directly references recreational activities, other ordinances address stewardship of resources that indirectly contribute to the quality and variety of recreational opportunities. Examples of such direct and indirect mandates are described in **Table 9-2**.

TABLE 9-2
Laws, Regulations, Ordinances, And Programs Relevant to Ohio River Recreation

Law/Program	Key Components	Relevance to Recreation
Directly Relevant to Recreation at Corps Projects or Cost Sharing With Other Sponsors		
Federal Water Project Recreation Act (16 U.S.C. 460*l*-12).	Establishes policy that consideration be given to opportunities for outdoor recreation and fish and wildlife enhancement in the investigating and planning of Federal navigation, flood control, reclamation, hydroelectric or multi-purpose water resource projects, whenever any such project can reasonably serve either or both purposes consistently. May include recreation & wildlife benefits in project cost/benefit analysis.	On Ohio River, basis for boat ramps and shore fishing access to project pools, other facilities cost shared with state/local operators.
Reclamation Projects Authorization and Adjustments Act of 1992 Title XXVIII (16 U.S.C. 460*l*-31 - 460*l*-34), the *Reclamation Recreation Management Act*	Amends provisions of the Federal Water Project Recreation Act regarding cost sharing requirements for the provision of new recreation facilities, for recreation and fish and wildlife enhancement, and for the expansion or modification of existing recreation facilities.	Requirement for sponsor to assume 100% of operations, maintenance, and replacement costs is changed to "not less than one half the costs (16 U.S.C. 460*l*-13(a))." *These amendments extend to the Corps as well. Civil Works policy continues to require 100% non-Federal operations, maintenance, and replacement costs.*
National Trails System Act 16 U.S.C. §§ 1241 - 1251	Acknowledges the increasing popularity of outdoor recreation, the need to promote access to and enjoyment of outdoor areas of the Nation, both near urban areas and in more remote scenic areas.	Corps recognizes that the aesthetic attractiveness of scenic corridors available on project lands can be enhanced by incorporation of trails or trail systems.
Flood Control Act of 1944	Authorizes the Corps, to construct, maintain and operate public park and recreational facilities at water resources development projects (includes non-reservoir projects). Local interests also permitted to construct, operate and maintain such facilities.	Water areas of all such projects shall be open to public use for general recreational purposes, includes public access.
Relevant to Protection of Natural Resources for Recreational and Other Values		
Fish and Wildlife Conservation Act	Act declares that fish and wildlife are of ecological, educational, esthetic, cultural, recreational, economic and scientific value to the Nation.	May provide financial and technical assistance to States to conduct inventories and conservation plans for non-game wildlife.
Fish and Wildlife Conservation and Water Resource Developments-Coordination (16 U.S.C. § 661 et	Recognizes contribution of wildlife resources to national interests, provides that wildlife conservation receive equal consideration and be coordinated with other features of water-resources development programs.	Requires consultation with F&WS, state wildlife agencies from early planning to project completion. Provides for the use of

Law/Program	Key Components	Relevance to Recreation
seq.)		Civil Works projects for conservation, maintenance and management of fish and wildlife resources and wildlife habitat.
Emergency Wetlands Resources Act of 1986 (16 U.S.C. §§ 3901-3932)	Purpose is to promote the conservation of wetlands to maintain the public benefits they provide, and to fulfill international obligations contained in various migratory bird treaties and conventions (16 U.S.C. 3901 (b)). The means for this identified in the Act include: cooperative management and conservation efforts among private interests, local, state and Federal governments; and acquisition in fee, easements or other interests and methods.	Regional offices of the USFWS develop Regional Wetland Concept Plans, which may be useful in identifying significant opportunities for ecosystem restoration. Maps and other information from the National Wetlands Inventory may be useful in Civil Works planning and natural resources management initiatives.
Relevant to Protection of Historic Resources for Recreational and Other Values		
National Historic Preservation Act of 1966 (16 U.S.C. §§ 470 et seq.)	Act establishes preservation as a national policy and directs the Federal government to provide leadership in preserving, restoring and maintaining the historic and cultural environment of the Nation.	Corps has the opportunity to provide leadership in the preservation of cultural resources and to protect sites and structures as part of the operation and maintenance of Corps projects.
Archeological Resources Protection Act of 1979 (16 U.S.C. § 470 et seq.)	Enacted to preserve and protect resources and sites on Federal and Indian lands. Prohibits the removal, sale, receipt, and interstate transportation of archaeological resources obtained illegally (i.e., without permits) from public or Indian lands	Authorizes Federal agency permit procedures for investigations of archeological resources on public lands under the agency's control.

9.7 PAST TO CURRENT BASELINE CONDITIONS

9.7.1 Early Recreational Activities

Popularity of the Ohio River as a setting for recreational activity dates back to well before the beginning date (1920) for this assessment. The advent of steamboat transportation in the early 19th Century introduced luxury travel to the Ohio River for those that could afford it. First class accommodations featured luxury staterooms, fine dining, gambling, music and live entertainment, whether traveling for business or pleasure (Blake, 1981). Before long, some steamboats were entirely converted for use as floating entertainment centers. William Chapman's *Floating Theater*, built in Pittsburgh and launched on the Ohio River, made its initial trek to New Orleans in the summer of 1831 (Baldwin, 1981). Showboats provided a variety of entertainments, including dining, jazz, blues, popular music, theater, and vaudeville, for over a century. The showboat *Majestic*, built in Cincinnati in 1923, was by 1939 the last floating theater operating on the Ohio River (Baldwin, 1981). Now moored at the Cincinnati Public Landing, the *Majestic* still offers a summer theater series on the river.

Commercial steamboat transportation declined through the mid 19th Century due to competition from the railroads, but the entertainment value of traveling by steamboat survived. Vacation travel on steamboats offered all the luxuries of business travel during the earlier era and remained popular well into the 20th century. In addition to this overnight travel service, numerous excursion boats began operating on the river. While some provided transportation to a specific destination such as Cincinnati's Coney Island, most simply provided 2 or 3 hour tours on the river. These boats were designed to carry 1,000 to 5,000 people for the purpose of providing a floating platform for dining, sightseeing, and other entertainment (Blake, 1981).

By the turn of the 20th century, individual and family oriented activities such as pleasure boating, fishing, swimming, and picnicking were all highly popular pastimes on the Ohio River. Prior to completion of the low-level navigation dams (1929 or earlier, depending on location), summer low water in the Cincinnati area would reveal miles of smooth sandy beaches. On weekends, they were a popular site for family outings, where people could boat, fish, swim, and picnic (Roberts, 1981).

As completion of the low-level dams progressed through the 1920s, a variety of factors began to influence recreational activities on and around the river. The nature of such changes varied significantly at different locations along the river. Along the heavily industrialized reaches from Pittsburgh through Wheeling, steel mills, other industry, and railroad lines crowded out residential and commercial uses of the floodplains while also discharging their industrial process effluents to the river. The combination of pollution and restricted access eliminated most recreational activities and contributed to negative perceptions of the river's recreational potential that persisted well into the 1970s (Muller, 1972). Downstream from the industrialized reaches; acidic mining wastes destroyed aquatic life and rendered much of the river unusable for recreational activities. By contrast, significant recreational activity in the Cincinnati area persisted well into the 1930s and began to come back (concurrently with improving water quality) during the 1960s. Downstream from Cincinnati, rural stretches of the river were less impacted by industrial, mining, or municipal wastes and recreational patterns probably persisted with relatively less disruption.

The navigation dams had mixed impacts on some recreational patterns. The low water beaches were eliminated and fisheries associated with shallow riffles were restricted to tailwater areas immediately downstream of the dams. However, most references cited in this chapter suggest that changes in water quality engendered the most dramatic impacts to recreational activities. Coordinated efforts to clean up the Ohio River date from the establishment of the Ohio River Valley Sanitation Commission (ORSANCO) in 1948, and early successes in many areas contributed to reestablishment of traditional recreational uses from approximately the mid-1960s. This period roughly corresponds to the era of completion of the high lift lock and dam projects that replaced the earlier wicket dams. Thus, at least for the upper and middle reaches of the river, the recovery and expansion of river oriented recreation occurred in the relatively stable environment of the long pools behind the high lift dams.

Graydon DeCamp, a *Cincinnati Enquirer* reporter and frequent boater during the early years of recovery, has written of trips to relatively unspoiled reaches of the Ohio mainstem during that time. He estimated that in 1981 about 2,000 boats were moored all

summer at marinas and docks near Cincinnati. Most boats were small houseboats and cabin cruisers (20-25 ft. in length), a few were yachts (≥65 ft.), and many were smaller cabin boats and runabouts (16-20 ft. in length). A typical marina at the time consisted of a "headboat", essentially an old barge moored to the shore by heavy steel cables and to the river bottom with massive concrete "deadmen". Two long strings of floating docks were attached to the headboat and extended downstream a few hundred feet. Both the headboat and docks rose and fell with the river levels and were anchored by steel posts called "spuds". At the end of the boating season in late fall, the headboats were hauled close to shore and the floating docks were taken out of the river. Because of the winter hazards of high water, driftwood, and, possibly, ice, only a few harbors in protected embayments and tributaries remained afloat all year (DeCamp, 1981).

9.7.2 Present Status and Recent Trends

Over the past 30 years or more, the popularity of the Ohio River as a setting for recreational activities has experienced tremendous growth. People participate in a broad spectrum of river oriented activities both on and around the river. Despite this broad and apparently expanding spectrum of recreational interests, most readily available studies of Ohio River recreation have focused on boating and fishing activities. This is partly due to their status as primary on-the-water forms of recreation, partly the result of boat registrations and fishing licenses that facilitate tracking these activities, and partly the existence of state agencies responsible for managing these activities. Although narrowly focused, such studies do illustrate recent trends in boating and fishing that may be applicable to analysis of the broader spectrum of recreational activities.

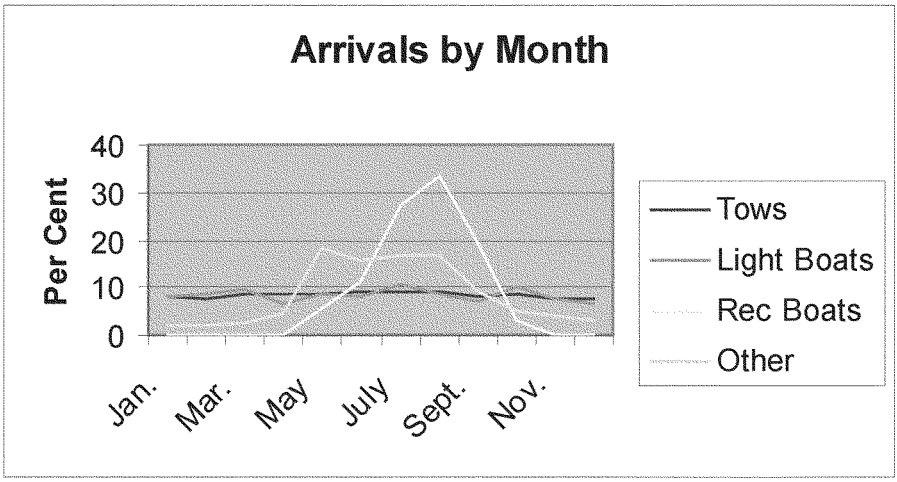
9.7.2.1 Recreational Boat Lockage Data

The Corps maintains records of all boat traffic that utilizes its locks on the Ohio River. Every boat that transits a lock is classified as a tow, light boat (other commercial boats), recreational boat, or other (includes excursion boats). Comparison of lock arrival times for commercial and recreational boats illustrates the basic patterns of boating activity on the Ohio River. Recreational boats are generally operated during daylight hours, on weekends, in the warm season of the year. **Figures 9-1-through 9-3** illustrate the extent to which recreational boats adhere to this pattern at Emsworth Lock and Dam. Tows and other commercial boats operate year-round, 24 hours per day, resulting in lock arrival times that approach a flat line. Arrival patterns for 'other' boats at this location (Emsworth Lock, 1998) illustrate the May-August season and Monday-Saturday, mid-day operations of the excursion boats.

Figure 9-4 summarizes total recreational boat lockages at all 20 Ohio River lock and dam projects for the last six years of record. Lockage records do not directly reflect all boating activity on the river because the relatively large size of Ohio River pools and general availability of access and boater services makes 'same pool' boating a feasible option. However, many pleasure boaters choose to include lock transits in their boating itinerary. The highest numbers of boats lock through Meldahl, with Markland a close second. Cincinnati is located approximately midway between these projects and likely contributes to the high numbers of boats using these locks. By contrast, McAlpine Lock and Dam is located in downtown Louisville, allowing boaters to launch either above or below the dam and thus minimize use of these locks. Additionally, construction of a new

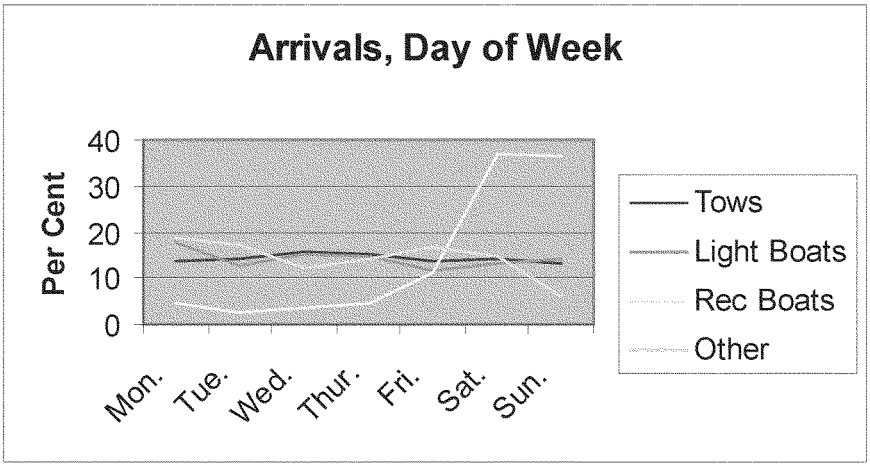
1200-foot lock extension at McAlpine during this record period may have reduced recreational use of these locks. The high numbers of lockages at the upper four projects (Emsworth, Dashields, Montgomery, and New Cumberland) reflect boating activity in the Pittsburgh area. Pools at these locations are also much shorter than downstream pools, which contributes to more frequent lockages.

FIGURE 9-1
Lock Arrivals by Month, Emsworth Dam, 1998



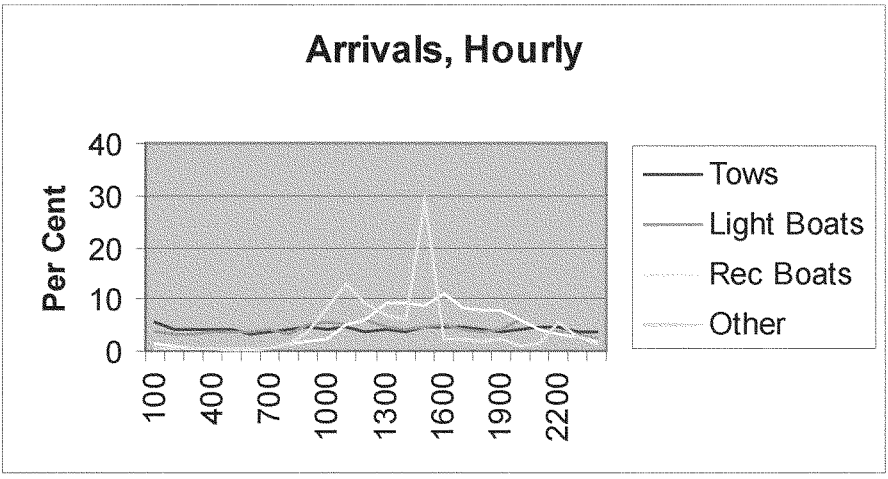
Source: U.S. Army Corps of Engineers

FIGURE 9-2
Lock Arrivals by Day of Week, Emsworth Dam, 1998



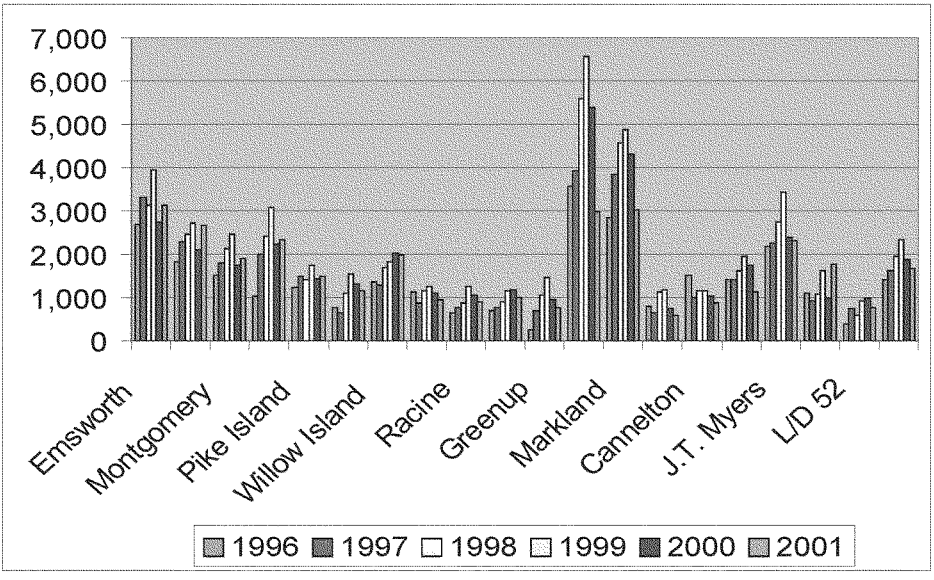
Source: Source: U.S. Army Corps of Engineers

FIGURE 9-3
Lock Arrivals by Time of Day, Emsworth Dam, 1998



Source: Source: U.S. Army Corps of Engineers

FIGURE 9-4
Total Recreational Boat Lockages on Ohio River



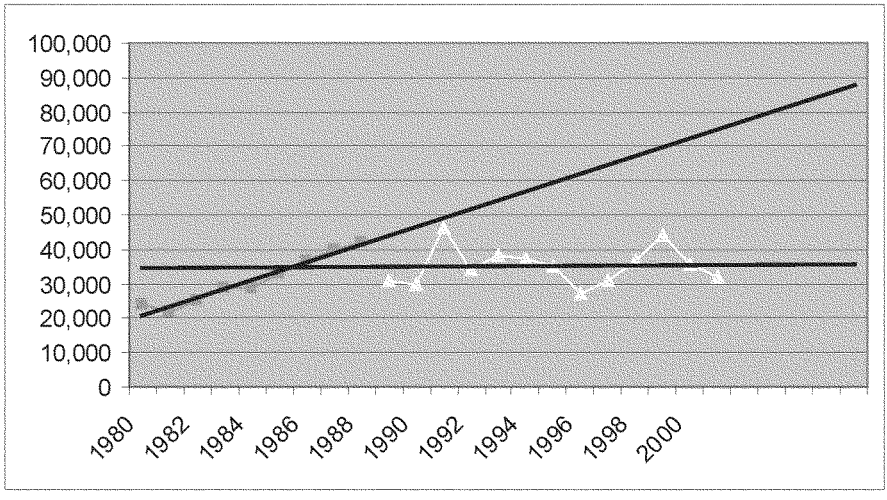
Source: U.S. Army Corps of Engineers

Lockage patterns illustrated in **Figure 9-4** also reflect annual variations in recreational boating opportunity associated with weather and water conditions during the

May-September peak season. Both good (1999) and bad (1996) years exhibit fairly consistent patterns at locations up and down the river. High water and inclement weather generally affect the full length of the river and, consequently, preclude traveling up or downstream to less impacted locations.

When aggregated for the total river and tracked for the long term, recreational lockages reflect a steady growth trend for boating on the Ohio River from 1980 through 1988 and almost no growth from 1988 through 2001. Total lockages for the two periods are illustrated below in **Figure 9-5**. The rapid growth of lockage activity from 1980 to 1988 may reflect renewed interest due to improved water quality. The trend from 1988 to 2001 could be influenced by a variety of factors, including annual variations in river water levels, changes in boating travel patterns or improved availability of launch ramps (which could reduce the need to lock through from available ramps to preferred pools). The latter trend may also reflect the end point for rediscovery of the river, i.e., all boaters in the region are aware of opportunities on the river and the level of interest has stabilized.

FIGURE 9-5
Total Recreational Boat Lockages and Trends on the Ohio River



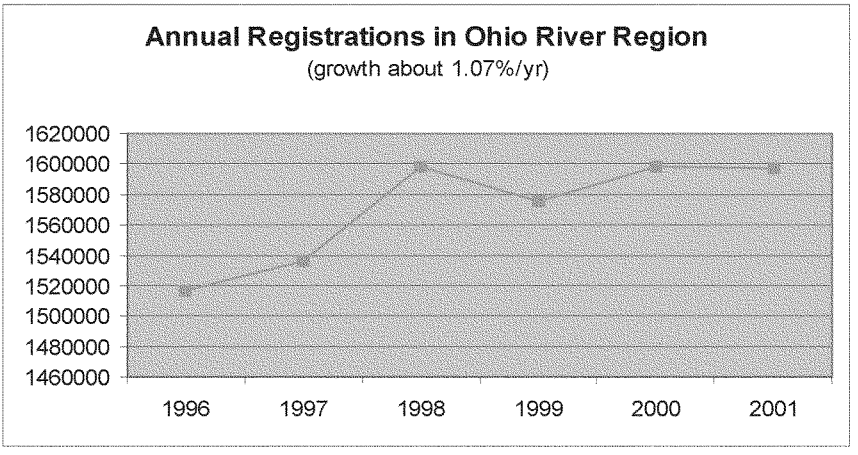
Source: U.S. Army Corps of Engineers

9.7.2.2 Boat Registration Data.

Nationwide annual recreational boat registrations have climbed steadily from a total of approximately 7,976,000 in 1977 to about 12,876,000 in 2001. This represents an average annual growth of 2.7 percent. However, the rate at which boat registrations have increased has declined over the more recent periods of record. Growth during the past 20 years averaged 2.3 percent annually, during the past 10 years averaged 1.9 percent annually, and fell to an average annual growth of 1.1 percent during the past 5 years (USCG, 2002).

Recent annual registration data (1996-2001) are available for individual states in the Ohio River region and recent county data are available for Ohio (1995-2001) and Pennsylvania (1992-2001). The states generally reflect both the national average boat registrations per capita and the recent national trend towards a slower rate of growth, with an average annual growth for the region of 1.1 percent during the past 6 years. Growth rates for individual states range from a low of 0.04% for Indiana to a high of 2.8% annually for West Virginia. **Figure 9-6** presents recent boat registrations for the six states bordering the Ohio River and **Figure 9-7** presents similar data for Ohio and Pennsylvania counties adjacent to the river.

FIGURE 9-6
Recent Trend in Boat Registrations for States in Ohio River Region



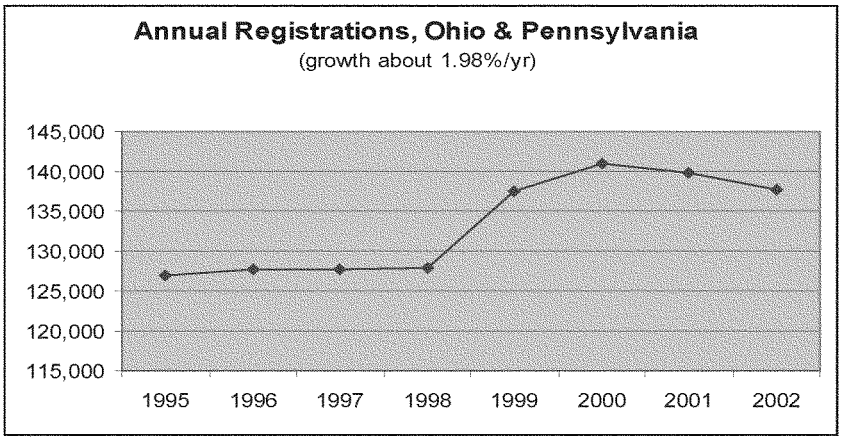
Source: USCG 2001

9.7.2.3 Studies of Boat Owners

The Ohio Department of Natural Resources (ODNR), Division of Watercraft has recently completed a series of boating studies that help to illustrate boater activity on the Ohio River. In 1998, a survey of 5,544 boater households resulted in 2,339 responses for a response rate of 42 percent. The typical boat owning household took 15.7 boating trips to Ohio sites during the survey period (Oct. 1, 1997 through Sept. 30, 1998) and 2.1 trips outside of Ohio. About 81 percent of the Ohio trips were single day outings, while 19 percent were overnight or longer. Of the trips within Ohio, 4.3 out of 15.7 were to Lake Erie, 1.3 to the Ohio River, 8.7 to inland lakes and reservoirs, and 1.5 to inland rivers or streams. These averages suggest that about 8.3 percent of statewide boating activity occurred on the Ohio River during the study period **(see Figure 9-8)**.

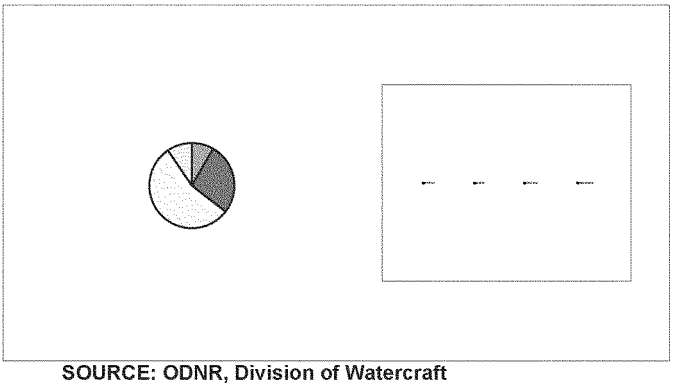
Boat ownership averaged 1.74 boats per household. Approximately 70 percent of boats were kept at home during the boating season and about 75 percent at home during the off-season. Thirteen percent were docked at a marina or club during the boating season and 3 percent were kept in dry-rack storage. The average one-way distance from home to the boating site was 38 miles.

FIGURE 9-7
Recent Trend in Boat Registrations for Counties Adjacent to Ohio River



Source: Ohio DNR, 2003; PA Fish and Boat Commission, 2003.

FIGURE 9-8
Destinations of Boat Trips Taken in Ohio by Ohio Boaters - 1998



SOURCE: ODNR, Division of Watercraft

Boater households spent an average of $134.30 per trip, for total expenditures of $2,104 per household for trips within Ohio during the study period. There were an estimated 234,303 boat-owning households in Ohio, resulting in an estimated $493 million in total household trip expenditures for trips within Ohio. When all costs of purchasing, repairs and maintenance were added to trip expenditures, total expenditures for boating households in Ohio added up to $1,387.3 million (Husak, 1999).

The Ohio Division of Watercraft completed a follow-up survey of boater households in 2002 (ODNR 2003). This survey was designed from focus group studies completed by the Division in 1991 and was intended to develop further information about boaters' experiences with issue areas identified in the focus groups. The survey collected information from 1,126 boater households that had actually boated on an Ohio waterway in

2002. Among these respondents, 5.8 percent listed the Ohio River as the waterway that they frequented most often.

The ODNR Division of Watercraft provided the ORMSS project with a breakdown of selected variables that identified the responses of Ohio River boaters. These variables included satisfaction with availability of launch ramps, experiences with silt and natural debris accumulations, overnight boating trips, and perceived need for speed limits.

A total of 18 of the 65 Ohio River boaters (27.7%) reported staying overnight on their boat while traveling on the river. Also, 100 of the 348 Lake Erie boaters (28.7%) and 30 of the 705 boaters on inland waters (4.3%) reported staying overnight while boating. Many Ohio River boaters (7 of 18 = 38.9%) tied up along the shoreline, but not in a designated boat camping area. Others were about equally divided among anchored in open water, tied up at a transient rental dock, tied up at a private dock (such as friend or relative), and use of a designated boat camping area. On Lake Erie, 73% stayed at transient docks.

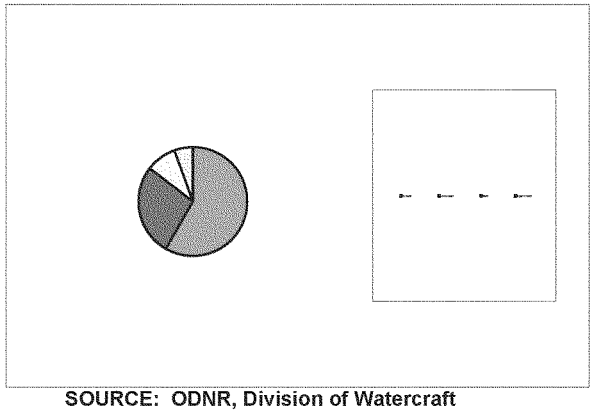
On the Ohio River, 50% of overnight boats traveled alone while 50% traveled in small groups of two to five boats. The most important destination features for overnight travel include 'suitable draft for boat' and experiencing a 'back to nature atmosphere'. Of secondary importance were nearby restaurants and short-term rental docks. Least important were city atmosphere, nearby tourist attractions, and nearby shops.

Of Ohio boaters in general, Ohio River boaters were least likely to report a need for speed limits. About 58 percent reported 'no need', 27 percent saw 'some need', 9 percent agreed to 'need', and 5.5 percent felt there was an 'urgent need' **(Figure 9-9)**. Those reporting 'no need' on other waterways ranged from 15 to 52 percent.

Also in Ohio, Ohio River boaters reported a lower satisfaction (12 of 59 respondents) with the availability of launch ramps compared to boaters using other Ohio waterways. Survey respondents rated their satisfaction on a scale of 1 (completely satisfied) to 5 (completely dissatisfied). Ohio River boaters in Southwest Ohio scored 2.81 while boaters from Southeast Ohio scored a somewhat more positive 2.39. The statewide average for the Ohio River was 2.61, while the statewide score for Lake Erie was 2.32. Scores for inland lakes averaged approximately 2.2.

Also, proportionally more Ohio River boaters (48.3%) reported negative impacts from accumulation of silt in the waterways. In other areas, problems were reported by 30.5% to 47.3% of respondents. Further, proportionally more Ohio River boaters (62.5%) reported negative impacts from accumulation of natural debris in the waterways. Problems reported for other areas ranged from 27.8% to 51.5% (ODNR, 2003).

FIGURE 9-9
Ohio River Boaters' Responses Regarding Need for Speed Limits



SOURCE: ODNR, Division of Watercraft

9.7.2.4 Boating/Fishing Studies

The ODNR, Division of Wildlife conducted a recreational use survey for Ohio's portion of the Ohio River in 1992 and 1993 (Schell et al., 1996). The primary objective of this survey was to provide direction and prioritization in developing fisheries strategies, resource protection, recreational facilities development, and public perceptions of the resource.

West Virginia had conducted a similar survey in 1981 of recreational activity on the eight Ohio River counties that border the state (Pierce et al. 1983). When Ohio prepared to conduct the 1992 survey, the Division of Wildlife coordinated with West Virginia to insure comparability of findings from the two surveys. As a result, comparisons can be made for several types of activity on the eight pools addressed by both surveys.

Two survey procedures were employed by both studies. Aerial surveys provided counts of boats and shore anglers and are summarized below in **Table 9-3**. The 1981 data collected by West Virginia is based on 66 aerial surveys – one weekend and one weekday flight per week, including holidays over more than 30 weeks. The 1992 data resulted from 90 aerial surveys – one weekend day and two weekday flights per week, excluding holidays during the approximately 30 week recreation season. While these counts are not directly comparable, they do illustrate strong growth for all activities observed.

On-the-water observations and surveys of shore and boat anglers were employed to augment the aerial surveys and generate estimates of fishing effort, including length of time spent fishing, species sought, and catch rates. Comparison of the surveys indicated that the total angler hours for the Ohio River bordering West Virginia increased 110% between 1981 and 1992. Most of the growth was accounted for by boat fishing, which more than tripled between 1981 and 1992, (Schell et al., 1996). **Table 9-4** provides additional details of angler hours by areas fished.

TABLE 9-3

Comparison of Boats and Shore Anglers during 1981 and 1992 Surveys

	Total Shore Anglers	Total Boat Anglers	Total Anglers	Total Fishing Boats	Total Recreation Boats	Total Boats
1981 (WV)	9,797	3,352	13,149	1,687	8,201	9,888
1992 (OH)	12,429	13,306	25,735	7,217	10,200	17,417

Fishing Boats: Actively fishing or such use was imminent.
Recreational Boats: Motorized and non-motorized recreational craft (not fishing).
SOURCE: Schell et al., 1996

TABLE 9-4
Comparison by Angler Hours of Areas Fished during 1981 and 1992 Surveys

Anglers	Pools		Embayments		Tailwaters	
	1981	1992	1981	1992	1981	1992
Shore	438,000	373,586	34,600	23,686		
Boat	133,500	403,299	27,400	29,569		
Total	571,500	776,885	62,000	53,255	84,700*	675,608*

*90-95% of the tailwater fishery during these surveys was shoreline fishing, due to boating access restrictions in the tailwaters.
SOURCE: Schell et al. (1996)

Comparison of the data from Ohio and West Virginia for this portion of the river suggests that pleasure boating may have declined less or recovered earlier from the mid-20th century era of heaviest pollution. Fishing may require a relatively higher level of water quality than pleasure boating or may have been delayed during the years required for fish stocks to become reestablished in response to improving water quality.

Boating and fishing data collected by the ODNR survey in 1993 (Schell et al., 1996) suggests that urban boaters may be somewhat less likely to include fishing in their boating activities. The 1993 survey looked at the lower 3 pools adjacent to Ohio: Greenup, Meldahl, and Markland. The 1992 study looked at the upper pools from New Cumberland to Greenup. Greenup was studied in both years to help address potential seasonal differences between the two study years. On the upper pools in 1992, fishing from boats accounted for 40.8 percent of all boating activity. On the lower pools in 1993, fishing from boats accounted for only 18.4% of all boating activity.

Seasonal variability in fishing success and in non-fishing recreational activity may account for some of the observed differences. The ODNR study recorded significantly better fishing success in 1992 compared to 1993. On the Greenup pool, fishing activity increased by 6.8 percent from 1992 to 1993, but all other boating activity rose by 55.2 percent. Fishing activity in 1993 accounted for 25.7 percent of all boating activity on the Meldahl pool and 14.5 percent on the Markland pool. Additionally, all boating activity on Markland pool accounted for 53.3 percent of all boating activity observed on Greenup, Meldahl, and Markland pools in 1993.

Cincinnati is located at the approximate midpoint of the Markland pool and provides boaters with numerous marinas and boat launching facilities. As indicated in Figure 9-4, the locks immediately upstream (Meldahl) and downstream (Markland) of Cincinnati are by far the busiest locks for recreation boats on the Ohio River. This suggests that Cincinnati also contributes a significant number of boaters to these neighboring pools. The

popularity of fishing in the Meldahl pool may be due in part to Cincinnati boat anglers desire to avoid crowds and/or perceptions of relative fishing quality between the pools.

In 1992, a recreational use survey was conducted on the Ohio River in the Pittsburgh area (TES, Inc. et al. 1996). The study examined and interviewed recreationists on 40 miles of the Ohio River, 14.5 miles on the Allegheny, and 23.8 miles on the Monongahela. The purpose of this study was to characterize and quantify the various recreational uses of the rivers in the study area for planning and managing the future recreational development of the rivers.

The survey and interviews were used to calculate total recreational activity in the study area for calendar year 1992. The study estimated 110,000 user days of bank fishing activity, 16,500 user days of boat fishing, 113,000 user days of general boating activities other than fishing, and 264,000 user days of park utilization. All of these estimates are conservative; the study identifies various factors that contributed to undercounting of the studied activities. The relative proportion of boat fishing activity in the Pittsburgh study, 12.7 percent of all boating activity, may be comparable to the 14.5 percent found on Cincinnati's urban pool by the ODNR study in 1993.

Recreational activity on rivers in the Pittsburgh study area was strongly influenced by seasonal weather. About 67 percent of all boating and 55 percent of all fishing activity occurred during the June-August summer season. Park usage was more year-round, with 28% of the activity during spring, 39% in summer, 24% in fall, and 8% in winter.

Recreationists in this study area consisted primarily of local residents utilizing a close-to-home resource. Anglers traveled a median round-trip distance of 12 miles, boaters averaged 20 miles, and park users traveled 6 miles. While virtually all anglers and boaters traveled to their recreation site by car, van, or truck, about 53 percent of the park users walked or jogged. An additional 8.2 percent took the bus. The survey of park recreationists included Point Park in downtown Pittsburgh, where users traveled a median 8 miles round-trip. Median travel to other parks was as low as 1 or 2 miles.

Despite fairly high catch rates averaging just over three fish per hour, anglers near Pittsburgh generally rated fishing quality as 'poor' (about 38%) or 'fair' (28%). This was primarily due to concerns with water quality (pollution, dirty or unclear water, debris in river, can't eat the fish). Over 80 percent of anglers indicated that river problems affected their enjoyment of fishing.

About 18 percent of boating activity near Pittsburgh involved contact recreation, including water-skiing, swimming and tubing. Most boats had motors (89%) and most were 14 to 21 feet in length (72%). About 6 percent of boats surveyed traveled through a lock during their outing. River problems were of concern to over 88 percent of boaters. Unpolluted water and absence of debris were the characteristics of greatest importance. While 70 percent of boaters rated easy access as very important, only 17% mentioned lack of public access as a problem.

The majority of park users were there to walk or relax (63%). Other activities included physical activity (15%), eating (10.5%), playground use (5.5%), and other passive activities (6%). Compared to the longer time commitments required of fishing and

boating, park visits averaged just 55 minutes. Only about 27 percent of park users felt that river problems affected their enjoyment of park activities. Items rated as 'very important' to park user's enjoyment included easy access (73%), scenic beauty (65%), and unpolluted water (63%) (TES, Inc; et al. 1996).

9.7.2.5 Comparison with Other Studies

Some comparisons are possible between recreational activity on the Ohio River and recent studies conducted on the Upper Mississippi River-Illinois Waterway (UM-IWW). The UMR-IWW system has less commercial traffic, but more recreational boating than the Ohio River. The busiest individual locks for recreation on UMR-IWW had recent annual averages (1994-1997) of 19,202 (Lock#3, UMR), 12,404 (Lock#7, UMR), and 18,381 (Peoria, IWW). These numbers represent total recreational vessels locked through, which is the same enumeration method used for the Ohio River data. Data for the busiest recreational locks on the Ohio River are illustrated in **Table 9-5**.

TABLE 9-5
Total Recreational Vessels Locking Through at the Busiest Ohio River Locks, 1998-2001

Lock	Average No. of Vessels Locking Through	No. of Vessels for Busiest Year, 1998-2001
Meldahl	5,133	6,564
Markland	4,193	4,880
Emsworth	2,519	3,939

The UMR-IWW study found no conflict between commercial navigation and recreational boating. There was little or no correlation between delay times for commercial traffic and the number of recreational lockages. Locks accommodated heavy recreational traffic by increasing the number of boats per lockage. There was plenty of capacity for additional recreational lockages, with the busiest locks averaging 4.2, 3.3, and 3.7 recreational boats per lockage (U.S. Army Corps of Engineers, 1999).

A second study of the UMR-IWW system provided an estimate of total recreational boating activity for year 2000 by pool. Total boating days on the UMR-IWW were estimated to be 2.7 million, with the large majority of this activity (2.37 million) on the Upper Mississippi River. Comparison of the two UMR-IWW studies allows calculation of the ratio of boats locked to the total of boats in the system. For the total UMR-IWW system, about one boat in 17 locked through (U.S. Army Corps of Engineers, 2000b).

If one assumes the same ratio applies, on average, for the Ohio River, one can estimate total days of recreational boating from the recreational boat lockage data. This results in an estimated 535,239 recreational boating days on the Ohio River during 2001, based on 31,725 recreational boat lockages recorded. For the busiest year on record (1991), 46,347 recreational boat lockages would result in an estimate of 781,568 recreational boating days.

9.7.2.6 Riverfront Enhancement Trends

As this document reiterates, measurable improvements in water quality of the Ohio River mainstem have led to the rediscovery of the river as an asset to communities along the entire river corridor. During the earlier water quality recovery phase (1970s and 1980s), specific sites began to be developed for recreation and entertainment, for example, riverfront parks, major league stadiums, and riverboat restaurants. Within the past decade, however, riverfront projects have become much more comprehensive in scope. Large and small-scale efforts to integrate residential and commercial development, shoreline and river recreation, heritage tourism, and ecological protection/restoration are underway in many communities along the Ohio mainstem.

All three of the river's major metropolitan areas have organizations dedicated to regional visions for the river corridor:

- River Fields, Inc. (www.riverfields.org) is the oldest such organization, founded in 1959. It promotes management, protection, and development of land and water resources along both sides of a 50-mile reach of the river near Louisville from the community of Westport in Oldham County, KY (RM 580) to West Point in Hardin County, KY (RM 630). River Fields has played a key role in the reclamation of Louisville's waterfront and in the development and implementation of a master plan for a 39-mile greenway system along the Ohio River and four tributaries near Louisville.

- The more recently founded Ohio River Way (www.ohioriverway.org), based in Cincinnati, focuses on a 150-mile reach of the river from Maysville in Mason County, KY (RM 408-409) to Madison in Jefferson County, IN (RM 558-559). Ohio River Way's focal areas include recreation, commerce, ecology, heritage, and the arts. Among its long-term goals is the development of a 300-mile, multi-state greenway loop along the river corridor.

- The Pittsburgh Riverlife Task Force (www.pittsburghriverlife.org) was founded in 1999 to develop a compelling vision for the city's waterfront, an area encompassing portions of the Ohio, Allegheny, and Monongahela rivers. *"A Vision Plan for Pittsburgh's Waterfront"*, presented in 2001, focuses on providing "continuous public access to the rivers and along the edges, connecting and expanding on the parks that now punctuate the shoreline in a continuous flow of trails, bridges, green space and waterfront amenities". The series of interconnected places and destinations is envisioned to comprise a grand public space called "Three Rivers Park". Concurrently, the Western Pennsylvania Field Institute (www.wpfi.org) supports a program promoting outdoor recreation of all types on and along Emsworth Pool (Ohio RM 0-6.2).

Several smaller communities along the river have developed comprehensive planning processes or implemented plans that combine recreation, heritage tourism, and economic growth. Examples of such efforts include:

1) Designation of the 106-sq. mi. Wheeling National Heritage Area (WNHA), WV – This National Park Service program permits designation of heritage areas "where

natural, cultural, historic, and recreational resources combine to form a cohesive nationally distinctive landscape" (www.cr.nps.gov/heritageareas/). An important component of the Wheeling project has been the development of the Heritage Port, a 20-acre landing/entertainment complex, serving as a concert and festival venue.

2) Development of Marietta, OH, as a heritage tourism base – Marietta has capitalized on its river location and status as Ohio's first city to become a center of heritage tourism. The downtown riverfront offers specialty shops, historic lodging, museums, and trolley transportation. Nearby places of interest include Blennerhassett Island State Park and the Ohio River Islands National Wildlife Refuge.

3) Greenway planning near Evansville, IN – Progress is being made on the Pigeon Creek Greenway Passage, a 42-mile greenway encircling Evansville with portions of the route following the Ohio River levee and traversing the renovated downtown. Additional plans include connections with the river town of Newburgh and with Angel Mounds Historic Site.

4) Renaissance of Paducah, KY – Historic building restoration, live entertainment downtown on Saturday nights (May-September), riverboat visits, museums, and self-guided walking tours attract visitors to the most downstream sizeable community on the Ohio River in Kentucky. A $40 million, year-round performing arts center opened in February, 2004, at the downtown floodwall. A series of floodwall murals depicting Paducah's history has become an interesting visitor attraction. The mural artist is painting a similar series on the floodwall in Covington, KY.

5) Comprehensive planning in Southwestern Illinois – The Southern Five Region, which includes Alexander, John, Massac, Pulaski, and Union counties in the Ohio River corridor in Southwestern Illinois, has recently completed a regional economic development plan. The plan's strategies include protecting, enhancing, and creating tourism and outdoor recreation areas as well as developing new service areas and recreation infrastructure. Just east of the Southern Five Region a river taxi connects tourists visiting river towns in Gallatin and Hardin counties.

Many other smaller communities along the river are developing docking facilities, rejuvenating their downtowns, and hosting river-based festivals focusing on regional music, art, food, and other local attractions (e.g., the Superman festival in Metropolis, IL). Widespread Internet access has become increasingly important in publicizing recreation and entertainment offerings of smaller river communities.

The Ohio River Scenic Byway (www.byways.org/browse/byways/2286) connects communities and points of interest along the 943-mile north bank of the Ohio mainstem through the states of Ohio, Indiana, and Illinois. Like other routes in the National Scenic Byways system, the Ohio River Scenic Byway markets and promotes all types of recreational, natural, scenic, and cultural features within at least one to two miles of the route. Maps and details on places of interest and amenities for motorists, bikers, and hikers are available on the web site above. This web site also features links to individual state web sites.

9.7.2.7 Recreation Support Facilities

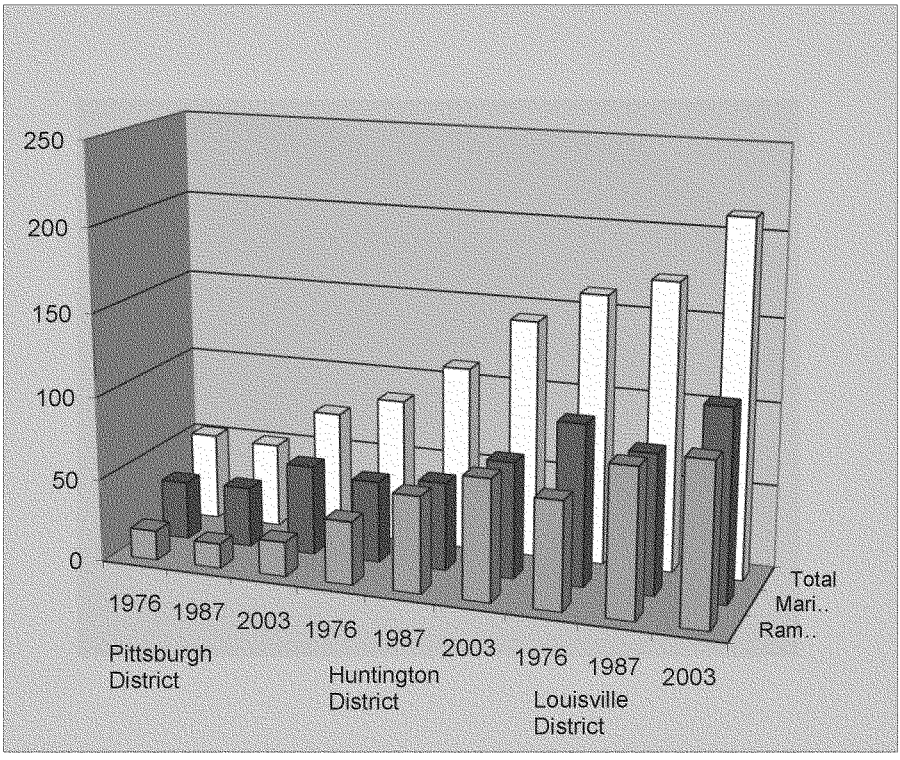
The growth and diversification of recreational activities on the Ohio River create demands for a variety of support facilities and services. Informal and qualitative data collected for this study suggest that steady growth is occurring in riverfront dining, camping, marinas, shopping, boat launching ramps, parks, and related services in response to this demand, although quantitative data for most of these trends is not readily available. However, numbers of marinas and public boat launching ramps can be tracked from Corps of Engineers Navigation Charts for the Ohio River. Data for the three past decades are presented in **Figure 9-10**.

The numbers of public ramps and marinas were primarily derived from Appendix B, Inventory of Small Boat Harbors, Ramps and Landings, published in the 2003 Ohio River Navigation Charts (U.S. Corps of Engineers, 2003). Facilities were classified as a private marina if they were described as a marina, boat club, harbor, or similar class of service, or if they provided services such as private launching ramp, fuel, or overnight mooring. Facilities that provided only restaurant or food sales were excluded, as were excursion boat terminals. Facilities were classified as a public ramp if described as such and owned by a public entity such as riverfront town, state wildlife agency, or the Corps. Listings that described privately owned docks or launching ramps were excluded. The list of facilities identified from Appendix B was then compared to the 2003 Navigation Charts. A few additional facilities that were clearly labeled on the charts as marinas or public ramps were added to the enumeration. A number of launching ramps appeared on the charts that were not listed in Appendix B. These were excluded from enumeration if unlabeled or if identified by the name of an individual or corporation. Additionally, mapped facilities that were labeled as closed or abandoned were excluded.

The 2003 Ohio River Navigation Charts included marinas and ramps located on tributaries to the Ohio River. These were included if located within 5 miles of the Ohio River or below the first lock and dam on the tributary river. In a few cases, the 1976 and 1987 charts did not include mapping of such tributaries. Where this occurred, facilities from the 2003 charts were excluded.

While this enumeration tracks the number of marinas operating on the Ohio River, it probably under-represents the overall service capacity provided. The enumeration does not address expansion of capacity at individual marinas. A few cases were noted where adjacent marinas shown on earlier charts appear to have merged into a single operation. The total count was thus reduced even though net service likely was not.

FIGURE 9-10
Ohio River Marinas and Public Ramps



Source: U. S. Army Corps of Engineers

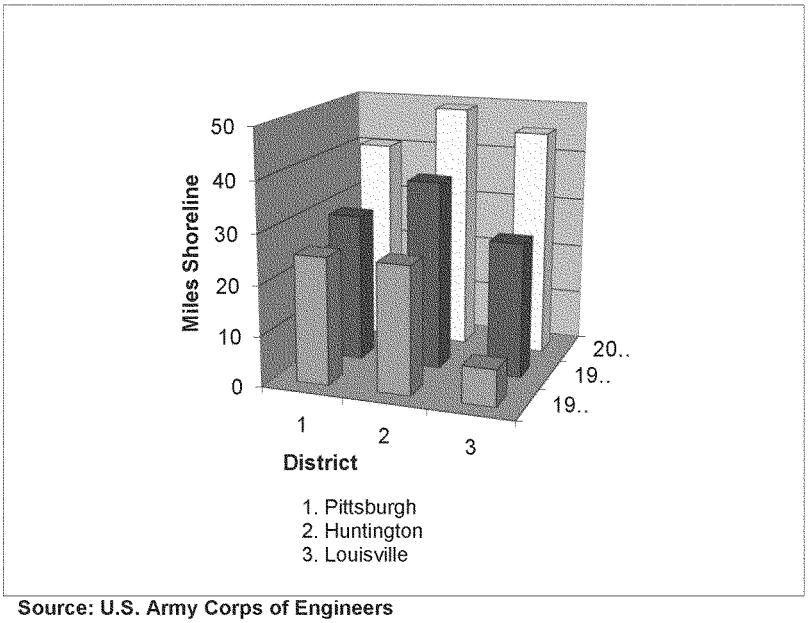
9.7.2.8 Fleeting Areas and Competing Uses of Ohio River Resources

Recreationists on the Ohio River must share the resource with commercial navigation. In addition to the size and number of barges and towboats on the water, the industry requires space for terminals and fleeting activities. Barge and tow activity is reflected in records of net tonnage of commerce shipped on the river (see Chapter 10, Transportation). Areas devoted to fleeting and terminal activity were calculated from Ohio River Navigation Charts, and are displayed in **Figure 9-11**.

Pittsburgh District mapping of 'Fleeting Areas' applies to both commercial dockage areas and to more remote locations where barges may be temporarily moored or anchored.

Huntington District mapping makes a distinction between commercial dockage areas (freight terminals) and 'fleeting harbors' for temporary barge moorage. Different map symbols are used for these two classifications. Interpreting both, as 'fleeting activity areas' would be most consistent with Pittsburgh District terminology. For consistency,

FIGURE 9-11
Mapped Fleeting Areas on the Ohio River



Source: U.S. Army Corps of Engineers

commercial docks were counted and assigned a value of 0.1-mile freight terminal activity unless otherwise mapped.

Louisville District mapping appears to apply 'Fleeting Areas' only to remote temporary moorage of barges. Freight terminal areas are illustrated as commercial docks and/or cells. The 'Fleeting Area' category in this district appears most directly comparable with the 'Fleeting Harbors' category in the Huntington District. Commercial docks were shown only as points in the 1987 and earlier charts, but are shown as stretches of mooring cells that could be measured for length in the 2003 charts. However, there is no basis for comparing changes in the areas of freight terminal activities from past to present. Therefore, past to present comparisons were only for fleeting harbors in the Louisville District.

For the total river, areas devoted to fleeting have increased by 233 per cent from 1976 to 2003. As of 2003, 135 miles of shoreline are used for fleeting activities, representing 6.9% of the Ohio River's total shoreline (981 miles x 2). The rate of increase has been steepest on the lower half of the river; fleeting areas have increased by over 600% in the Louisville District. Shoreline mileage utilized for fleeting activities on the Ohio River is summarized below in **Table 9-6**.

TABLE 9-6
Miles of Fleeting Activity on the Ohio River

Year	Pittsburgh District	Huntington District	Louisville District	Total
1976	25.3	25.3	7.3	57.9
1987	29.4	37.4	26.8	93.6
2003	40.7	49.1	45.1	134.9

Source: U.S. Army Corps of Engineers

9.8 INTERACTIONS WITH OTHER VALUED ENVIRONMENTAL COMPONENTS (VECS)

Recreational activities on the Ohio River exhibit very high levels of interaction with water quality and biological resources. Water quality appears to be the primary factor affecting the attractiveness of most recreational activities. Recreation on and around the river declined wherever water pollution reached excessive levels and returned soon after water quality recovered. Water quality also impacted intermediate factors such as fishing quality, which subsequently affected recreational activity.

In addition to fisheries, the entire spectrum of biological resources impacts the variety and quality of recreational opportunities. Riparian corridors, islands, beaches, and embayments provide varied settings for river-based activities. The bluffs and wooded hillsides contribute a scenic backdrop for such activities plus a focus for sightseeing, scenic drives, relaxing outdoors, and other contemplative approaches to recreation. Recreational demand for these resources may contribute to public and private efforts to protect or enhance such resources.

Although both recreation and commercial navigation have grown significantly over the past several decades, these potentially conflicting activities have managed to coexist with a minimum of friction. The navigation industry trains for and maintains a high degree of professionalism among its operators, contributing to very low accident rates between commercial tows and recreational boaters (see Chapter 8, Health & Safety). Likewise, the U.S. Coast Guard, state agencies, and some municipalities have improved boating safety through development of improved safety equipment standards, requirements for boat operator training, and enforcement of operational rules such as reckless operation and consumption of alcohol. In highly congested areas, additional regulations such as no wake zones are employed to improve safety on the water. Both recreation and commercial navigation are expected to continue to grow, with attendant competition for space on the water and for marinas, terminals, and related support facilities on shore.

Important relationships exist between cultural resources and recreational activities along the Ohio River. Potential income from tourism has often helped motivate the identification, renovation, and protection of historic sites, buildings, and districts in riverfront communities. Similarly, recognition and protection of cultural features may be incorporated into the planning and design of parks, trails, scenic byways, greenways, and urban redevelopment projects.

General relationships between Ohio River recreational factors and other VECs are summarized in **Table 9-7**.

TABLE 9-7
Interactions of Recreation Factors with Other VECs

VEC	Factors & Impacts	Past/Present Trends	Future Trends	Comments
Water Quality	Improved water quality is principal factor underlying past and ongoing growth of recreational activity.	Growth of river oriented activity with improved water quality and accessibility.	Continued growth of river oriented activity with improved water quality and accessibility.	Recreational experience, activity contributes to demand for better water quality.
Biological Resources (aquatic, riparian, T&E).	Resource recoveries contribute to quality, variety of recreational experience.	Growth of river oriented activity with improved fisheries, scenic riparian landscape.	Expanding navigation, commercial/residential and recreational uses of river will conflict with habitat needs.	Long term protection/ management of Biological Resources required to maintain recreational quality, variety.
Transportation & Traffic	Mutual coexistence between commercial transportation and aquatic recreation.	Growth of both activities has not yet created major conflicts.	Continued growth of both activities may contribute to future conflicts, congestion.	Most recreationists accept barge navigation as part of scenic river environment.
Socio-economic & Environmental Justice	Expanding leisure time and disposable income per capita.	Growth of river oriented activity with expanded time and income.	Expanding variety of river-oriented activity. Potential conflicts from crowding or incompatible uses.	Continued growth of urban riverfront oriented development (housing, shopping, and recreation).
Health and Safety	Expanding river oriented activities contribute to expanding exposure to river related risks.	Water quality improvements, spill prevention & response, improved monitoring has reduced risks.	Continued expansion of river oriented activities require improved water quality & monitoring to maintain low risks.	Control of contaminant sources affecting water contact recreation and fish consumption issues has slowed following early gains.
Cultural Resources	Historic sites, districts, architecture add variety & quality to recreation experience.	Recreation growth, interest supports historic preservation and heritage tourism.	Continued growth of recreational interests in cultural heritage features.	Parks, trails, greenways, urban riverfront projects can all incorporate cultural resources in planning & design.
Air Quality	Particulate emissions and ozone formation can impair visibility.	Viewscapes, recreational quality have benefited from improved air quality.	Appears likely present air quality will be maintained or improved.	Haze from coal burning, other sources persists throughout Ohio River corridor.
Land Use	Residential, commercial developments compete with recreation for space.	About 40% of land in Ohio River corridor developed during past 20 years.	Conversion of open space for development appears likely to continue.	Opportunities exist to incorporate recreation, preservation values in development, redevelopment designs.

9.9 RELEVANT ACTIONS AFFECTING RECREATION

RFFAs were evaluated for recreation oriented issues utilizing the RFFA Matrix (see Exhibit A, Procedure and Methods, for discussion of RFFA matrix). The matrix evaluation process resulted in identification of 17 RFFAs with high or medium high importance for recreation and an additional 38 that were rated as having medium importance. Results of the RFFA evaluation for recreation resources are summarized in **Table 9-8** and discussed in further detail in text following the table.

TABLE 9-8
RFFA Cumulative Effects Matrix for Recreation VEC

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location On River[4]	Impact	Importance[5]
Navigation Investment Actions					
Lock Extensions/New Locks/ Replacement or Rehabilitation	A	H	SL	+	M
L&D Operation & Maintenance, Non-structural Improvements, Dam Replacement/Rehab	A	H	SL	+	M
Other Corps Actions					
Channel dredging/dredged material disposal	A	H	SL	-	M
Flood damage reduction projects					
levees/floodwalls	A	L	SL	-	M
dry dams, other projects off mainstem	A	H		+	M
nonstructural measures (relocation)	A	H	SL	+	M
Modification of Corps structures for env-onmental improvements (Sec. 1135)	A	M	SL	+	M
Environmental restoration of aquatic ecosystems (Sec. 206)	A	M	SL	+	M
Recreation facilities - Construction and O&M	A	H	SL	+	H
ERP Projects - 5 categories	A	M	SL	+	M/H
Port development (Sec. 107) and maintenance dredging	A	H	SL	-	H
Pool maintenance	A	H	E	+	M
"But for" Actions					
Commercial Navigation					
fleeting areas/barge storage	A	H	SL	-	H
terminals	A	H	SL	-	M
multi-modal sites	A	H	SL	-	M
increased traffic	2, 3	H	U	-	H
dispersed barge traffic	A	H	SL	-	M
accidents/spills	A	H	E	-	M
Hydropower on dams	A	H	SL	-	M
Recreation facilities: Construction/O&M	A	H	SL	+	H
Actions by Others					
Public lands acquisition and management	A	H	SL	+	H

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location On River[4]	Impact	Importance[5]
Floodplain development					
residential	A	M	SL	+/-	M
commercial	A	M	SL	-	M
industrial	A	M	SL	-	M
Private recreational sites: campgrounds, docks, seasonal trailer parks, etc.	A	H	R	+	M
Crossings					
bridges	A	H	SL	+/-	M
Marina development & operation	A	H	SL	+	H
Water -based recreation					
boating	A	H	E	+	H
fishing	A	H	E	+	H
PWCs	A	H	E	+	H
hunting	A	H	R	+	H
wildlife watching	A	H	E	+	H
sight-seeing	A	H	E	+	H
Silviculture	A	H	E	+	M
Agriculture	A	H	R	+/-	M
WWTP discharges					
municipal	A	H	SL	+	H
industrial	A	H	SL	+	M
onsite systems	A	H	SL	-	M
Stormwater discharges	A	H	SL	-	H
Brownfields redevelopment	A	H	SL	+	M
Trail/bikeway development	A	H	SL	+	H
Casinos	A	H	SL	+/-	M
Hazardous waste sites	A	M	SL	-	M
Natural Climatic Events					
floods	A	H	E	-	M
droughts	A	H	E	-	M
severe storms	A	H	E	-	M
Regulatory Environment					
More stringent standards for envir-onmental media, pollutant source control, pollution prevention	A	H	E	+	M
Wetland Mitigation Banking	A	H	SL	+	M
Farmland preservation	A	H	R	+	M
Agricultural discharges	A	H	R	+	M
Small navigation projects	A	H	SL	-	M
Boating safety regulations	A	H	E	+	M
ORSANCO monitoring program	A	H	E	+	M
Spill response	A	H	E	+	M
Environmental sustainability practices	A	H	E	+	M

[1] Reasonably Foreseeable Future Actions

[2] Time period in which the RFFA may occur: 1 = within 10 years, 2 = in 10 - 25 years, 3 = in 25 - 60 years, A = applicable to all time periods

[3] Occurrence probability or likelihood RFFA will happen: H = high, M = medium, L = low

[4] Location or setting on river where RFFA is expected to occur: E = along entire length of river, SL = specific location, e.g., locks and dams, U = urban setting, R = rural setting

[5] Importance of RFFA: H = high, M = medium, L = low

9.9.1 Navigation Investment Actions

- Lock Extension, Replacement, or Rehabilitation (Impact, +; Importance, M): Short-term negative impacts are associated with construction activity. Access through the locks during construction would likely be restricted to commercial vehicles. Long-term positive impacts would be realized as new, extended, or replaced locks would provide more efficient and dependable service to recreational boaters.

- L&D Operation & Maintenance, Non-structural Improvements, Dam Replacement/Rehab (Impact, + Importance, M): Maintenance activities generally contribute to long term safety and efficiency of lockage services to recreational users. Short-term suspension of service may occur during some lock repair closures.

9.9.2 Other Corps Actions

- Channel dredging/dredged material disposal (Impact, -; Importance, M) Localized and temporary impacts occur to recreational boaters in the area of dredging activity. Potential habitat benefits could include dredged materials being used to build up bars or islands and to create or enhance shallow water habitats. Other channel maintenance activities such as clearing snags can have negative impacts on sport fisheries and general aquatic habitat values. Snag clearing appears to cause an unnecessary resource impact when it occurs outside navigation channels.

- Flood damage reduction projects: levees/floodwalls (+/-, M): These projects protect people and infrastructure investments and reduce or eliminate potential damage costs in flood prone areas. Traditional construction of such projects restricted access to the riverbank. Urban renovation, riverfront parks/developments typically include re-establishing links to the river.

- Flood damage reduction projects: dry dams and other projects off mainstem (+, M): These actions would positively impact river-based recreation by easing flooding in the river. This would provide benefits by reducing river flood levels and velocities and minimizing debris, pollutants, and sediments washed into the river.

- Flood damage reduction projects: nonstructural measures (e.g., relocation) (+, M): Streamside buffers that reduce non-point source pollution would improve water quality, aquatic habitat important to fisheries, and make river use more enjoyable. The relationship of water quality to recreation was frequently cited in survey responses and focus interviews.

- Modification of Corps projects for environmental improvements (Sec. 1135) (+, M): Improved habitat would enhance recreational use of the river. Positive benefits to fisheries and aquatic and riparian resources enrich numerous recreational activities.

- Environmental restoration of aquatic ecosystems (Sec. 206) (+, M): Positive benefits to recreation would be derived from improved aquatic and riparian

resources. Benefits would include all types of 'resource oriented' recreation, plus economic, health, and aesthetic benefits.

- Recreation facilities - Construction and O&M (+, H): Positive, long-term impacts would be realized from continued development of facilities specifically designed for recreational use and access.

- Ecosystem Restoration Projects (+, M/H): Improved habitat will result in improved fisheries and increased bird use. Shoreline/river fishing, waterfowl hunting, and bird watching would benefit. River-based hiking, picnicking, and sightseeing would also benefit from enhanced aesthetics of more natural landscapes. Surveys and focus interviews frequently cited the correlation of habitat improvement with improved quality of recreation and aesthetics.

- Port development (Sec. 107) and maintenance dredging (-, H): Development of ports and dredging for navigation traffic in response to increased navigation use of the river would result in conflicts with recreational boaters. Port development and dredging will also result in loss of shallow water habitat and a concomitant loss of fisheries. Port development could contribute some impacts to aesthetics and affect boat use in the area.

- Pool maintenance (+, M): Pool stability benefits docks and other shoreline recreational infrastructure. Suggestions for restored hydrologic functions would improve habitats and benefit resource oriented recreation.

9.9.3 But-for Actions

- Commercial Navigation: fleeting areas/barge storage (-, H): Negative, long-term impacts are associated with conflicts between recreation and commercial activity around these facilities and loss of recreational use. The general perception of aesthetic loss would also affect river use in proximity to these areas. Loss of shallow water habitat would affect fishing, while loss of riparian habitat would impact fishing, birding, and duck hunting. Fleeting areas should be located away from shore when possible, using off shore mooring cells to reduce negative impacts to shoreline habitat, aquatic habitat, fisheries, and recreation. Use of "dead-man" mooring devices causes riparian habitat loss and degradation.

- Commercial Navigation: terminals & multi-modal sites (-, M): Commercial activity around these facilities would contribute to negative, long-term impacts to recreation. The general perception of aesthetic loss would also affect river use in proximity to such areas. Loss of shallow water habitat due to dredging, propeller wash, and scour would negatively affect fisheries. Loss of riparian habitat affects birding and duck hunting.

- Commercial Navigation: increased traffic (-, H): Conflicts between commercial vessels and recreational boats could lead to long-term negative impacts for recreation. The severity of crowding impacts is dependent on the carrying capacity of individual river segments. Negative cumulative impacts to sport and

commercial fisheries will likely occur since commercial towboats have been documented to cause adult and larval fish entrainment mortality.

- Commercial Navigation: dispersed barge traffic (-, M): Significant, short-term impacts occur due to the safety and environmental degradation effects of dispersed navigation. Navigation traffic outside shipping lanes presents a danger to small craft using these areas to fish or sightsee. This danger is related to direct contact or large wakes. Navigating outside the channel causes negative impacts to sensitive aquatic habitats, shorelines, and substrates, possibly affecting sport and commercial fisheries. Sport and commercial fisheries will also likely be affected by entrainment mortality.

- Commercial Navigation: accidents/spills (-, M): Short to medium range impacts associated with safety concerns is linked to exposure to spills. Secondary impacts would be loss of fish and other aquatic organisms and fouling of habitat.

- Small navigation projects (-, M): Negative impacts could occur in the immediate area of the small navigation project if there is increased river traffic. Depending on the nature of the project, impacts to recreation could include limited access, increased congestion, and other effects.

- Hydropower on dams (-, M): Negative impacts will occur to aquatic resources and fisheries unless mitigating flows are mandated.

- Recreation facilities: Construction and O&M (+, H): Positive, long-term impacts would occur due to an increase in facilities specifically designed to facilitate recreation.

9.9.4 Actions by Others

- Public lands acquisition and management (+, H): Such acquisitions are critical to the long term protection and restoration of habitats, open space, and recreational opportunities.

- Floodplain development: residential (+/-, M): Growth in residences along the river would generally support a growth in boating, PWCs, touring boats, and fishing as individuals have less distance to travel to participate. There would be growth in private docks and marinas to accommodate the local population. Floodplain development could necessitate dikes and levees with subsequent loss of aquatic/riparian resources and associated recreational opportunities.

- Floodplain development: commercial/industrial (-, M): Growth in commercial/industrial activity along the river would compete with recreation, agriculture, and other potential land uses. Floodplain development could necessitate dikes and levees with subsequent loss of aquatic/riparian resources and associated recreational opportunities.

- Private recreational sites, including campgrounds, docks, and seasonal trailer parks (+, M): Continued growth of these developments is likely to continue in rural

counties in response to demand for recreational facilities. These facilities may have a higher potential for negative habitat and water quality impacts compared to public parks.

- Crossings: bridges (+/-, M): New or expanded bridges can improve accessibility to an area and promote growth of recreational activity, demand for recreational lands, and services. Bridges also may stimulate residential/commercial growth resulting in overcrowding and loss of recreational opportunities.

- Marina development & operation (+, H): Positive, long-term impacts due to an increase in facilities specifically designed to facilitate recreation would occur. However, concentration of marinas in embayments can contribute to losses of wetland/riparian resources.

- Water-based recreation: boating, fishing (+, H): Conflicts exist among fishing, PWCs, navigation, and water-skiing. Most of this conflict is minimized due to typical time of day when use occurs. Fishing occurs more in early morning and evening while other uses tend to occur mid-day. Because of their duration, fishing tournaments can conflict with other river uses. Survey and focus interview respondents report a low level of conflicts; the river provides adequate space for multiple uses.

- Water-based recreation: PWCs (+/-, H): As PWC use increases, there is greater potential for user conflict between them and recreational boaters and fishing. Implementation of training requirements and licensing would help mitigate this impact. Survey and focus interview respondents also suggest enforcement of rules can reduce conflicts.

- Water-based recreation: hunting (+/-, H): No significant conflicts with hunting are expected as long as it continues to occur away from residential and other populated areas. Most hunting occurs at dawn and dusk, thus avoiding most conflict with other users. Long-term availability of hunting areas will continue to decline in response to floodplain development.

- Water-based recreation: wildlife watching, sightseeing (+, H): Survey and focus interview respondents indicate that passive forms of relaxing outdoors are the most popular forms of river oriented recreation. Aesthetic factors, solitude, peace and quiet are important to these user groups. Up to a point, urban development and commercial navigation are accepted as part of the river environment and viewscape.

- Silviculture (+, M): Wooded shorelines and islands would add to the aesthetics of the river and enhance the recreational experience. Trees also enhance aquatic and riparian resources, control erosion, and filter runoff. Harvesting of timber could affect aesthetics and could serve as a source for non-point runoff that would negatively affect recreational use of the river, but most commercial harvest can be managed to minimize such impacts and maintain compatibility with recreation and aesthetic values.

- Agriculture (+/-, M): Agriculture is a source of non-point runoff of sediment, fertilizer, and pesticides that can negatively affect recreational use of the river due to water quality impacts and effects on fish. Implementation of BMPs (wooded riparian corridors, grass swales, filter strips, etc.) reduces sediment and pollutant runoff. Agricultural activity negatively impacts corridor habitat by eliminating tree canopy and native plant communities. Conversely, agriculture would be considered very aesthetic by most river users and would not detract from the recreation experience.

- WWTP discharges: municipal, industrial (+, M/H): In general, WWTP operations and treatment of industrial discharges have made significant contributions to improved water quality and recreational uses of the river. Impacts depend on level of treatment, operational consistency, and water levels in the receiving stream. Toxicity, temperature, odors, and visual effects are potential negative impacts to recreation.

- WWTP discharges: onsite systems (-, M): Onsite systems tend to be less reliable than WWTPs and, depending on their locations and numbers, can negatively impact water quality and recreational use.

- Stormwater discharges (-, H): Stormwater discharges include CSOs, SSOs, and runoff from urban surfaces, which contribute to elevated bacteriological contamination that create health risks and aesthetic impacts for recreational users of the river.

- Brownfields redevelopment (+, M): Many brownfields are being developed into mixed commercial, residential, and industrial uses. Developments are often up-scale and use the river as an asset. Depending on the river amenities added to these developments, the effects on recreation have generally been positive.

- Trail/bikeway development (+, H): Positive, long-term impacts result from an increase in such facilities. Forested or open park landscape, plus trail and infrastructure design contribute to environmental benefits, including viewscape protection. Survey and focus interview respondents also note importance of pedestrian connectivity and riverfront access to success of mixed-use riverfront developments.

- Casinos (+/-, M): Casinos may compete with marinas for space in embayments and contribute to loss of wetland and riparian habitats. Casino gambling generates mixed reactions among survey respondents.

- Hazardous waste sites (-, M): Unmanaged sites can cause a wide range of environmental damage with negative impacts to recreational use and aquatic life. Remediation or stabilized containment and long term monitoring is required to minimize negative impacts. (See also comments under Brownfields.)

9.9.5 Natural Climatic Events

- Floods and severe storms (-, M): Periodic impacts occur to all forms of recreation during and immediately after such events due to safety considerations. Rising water would affect all boats. Floating debris creates safety and aesthetics problems. Medium importance due to infrequency of events.

- Drought (-, M): Severe droughts could have a significant impact on recreation. The lowering of the river level decreases the surface acreage thereby increasing the potential for conflict. Less water also means less dilution of pollutants, thus decreasing water quality. Medium importance due to infrequency of events.

9.9.6 Regulatory Environment

- More stringent quality standards for environmental media, pollutant source control, and pollution prevention (+, M): Long-term positive impacts would be associated with improved environmental conditions. The river becomes a more enjoyable place to play.

- Wetland Mitigation Banking (+, M): This activity would benefit recreation by reducing run-off, improving habitat, and providing recreational opportunities.

- Farmland preservation (+, M): These programs are becoming important components of efforts to preserve open space and wildlife habitat and to control runoff. Preserved farmland creates incentives to implement agricultural BMPs (see agricultural discharges).

- Agricultural discharges (+, M): Implementation of BMPs (wooded riparian corridors, grass swales, filter strips, etc.) contributes to reduced sediment and pollutant runoff. Stronger incentives are needed to expand participation.

- Boating safety regulations (+, M): Some beneficial impacts could result if boater and PWC user behaviors are modified through education and enforcement of common sense rules. Conflicts among users and perceptions of crowding can be reduced through regulation of individual behaviors.

- ORSANCO monitoring program (+, H): Monitoring programs for the Ohio River provide data to states and others for management and enforcement responsibilities and contributes to maintenance of water quality. Though ORSANCO has no statutory authority, it does educate the public, public officials, and industry on water quality status.

- Spill response (+, M): Effectiveness of spill prevention, monitoring, and response programs reduces spills and minimizes damages from spills that do occur.

- Environmental sustainability practices (+, M): Provides a benchmark for evaluating present and desired future uses of the river and its resources.

9.10 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

One of the seven environmental operating principles of the Corps is to strive to achieve environmental sustainability (ES). ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation, and maintenance to improve the quality of life for present and future generations. Accordingly, ES represents an "ultimate test" whereby the significance of CEs can be evaluated. This test is applicable for programmatic impact studies wherein a broad, "high altitude" perspective is utilized. An Analysis of Environmental Sustainability (AES) has been and is being used in several other programmatic studies by the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps:
(1) identification of "common effects" on recreation parameters from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix;
(2) selection of sustainability indicators for recreation, and their grouping, as appropriate; and
(3) consideration of the "connections" between the common effects and the indicator groups

The output of the AES consists of a qualitative (descriptive) discussion of the "connections", with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions – what is the current ES for recreation, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable – the composite conditions for the selected indicators of ES for recreation do not reflect conditions that would facilitate attainment of acceptable standards or would not maintain existing standards in concert with collective impacts of proposed activities.

- Marginally sustainable – the composite conditions for the selected indicators of ES are such that attainment of acceptable quality and variety of recreational opportunities is accomplished for the majority, but not all, of the potentially affected populations. However, the conditions of the indicators are somewhat tenuous both in location and likelihood of occurrences (in other words, the conditions are "borderline" for ES, and there are uncertainties regarding specific quantitative measures for the ES of recreation for the Ohio River).

- Sustainable – the composite conditions for the selected indicators of ES are such that the attainment of acceptable quality and variety of recreational opportunities is accomplished for essentially all of the potentially affected populations in the Ohio River Valley, and such standards are maintained in concert with foreseeable future activity. Further, the conditions of the indicators exceed regulatory thresholds, and

various governmental programs are in place to respond to any potential erosion of recreational values.

Common effects of multiple actions have been previously discussed in the sections entitled "Interactions with Other VECs" and "Relevant Actions Affecting Recreation". Indicators or groups of indicators of ES were identified earlier in the section entitled "Indicators of Sustainability", and relevant information on them have been presented in the sections entitled "Past to Current Baseline Conditions" and "Recreation Surveys for ORMSS." For the purposes of this ES analysis, the sustainability indicators are associated with three tiers:

- first tier – "quantitative measures of recreation resource factors", for example, census information related to recreation opportunity or demand and ramp/marina counts from navigation charts

- second tier – "composite measures of recreation resource factors", for example, ramp/marina and fleeting area trends over time and survey trend questions related to future accessibility, and

- third tier – "composite indicators of recreation sustainability"; this includes measures developed from multiple indicators, for example, data on support for subsidized recreation infrastructure and on the busiest commercial pools.

Tables 9-9 and 9-10 include selected indicators of recreation sustainability. **Table 9-9** addresses the indicators of opportunity and accessibility. These indicators encompass general factors affecting one's ability to participate in the recreational opportunities provided by the Ohio River. The first column of **Table 9-9** lists examples of RFFAs associated with these indicators. General aspects of the maintenance, expansion, and operation of the Ohio River navigation system contribute to opportunity by providing stable pools, sufficient depth, and efficient, dependable service for recreational boaters. Included as principal RFFAs are actions that increase access (e.g., marina development and construction and maintenance of recreation facilities) and actions that can restrict access (e.g., port and terminal development and development or expansion of fleeting areas). From the discussion of RFFAs, it is apparent that many access-related actions have multiple effects. New or expanded highways and bridges, for example, increase river access and may lead to development of marinas and other facilities that support recreation. Marinas, however, may cause aquatic habitat damage/loss, which can reduce the overall quality of the recreation experience. Excessive recreation/commercial development resulting from transportation improvements also can result in localized congestion and competition. Limited resources such as embayments and wetlands, which constitute important habitats, desirable natural settings for recreation activity, and attractive sites for recreation oriented development, are particularly susceptible to such impacts. Thus, as one straightforward action leads to a series of other actions, a complex network of CEs can result that may be more than the "sum of its parts".

Table 9-10 considers actions related to the quality of recreation experiences. Experiences gained from participation in a recreational activity will directly influence future recreational choices. Likewise, public and private actions that contribute to maintenance or enhancement of recreational quality will be motivated by experience and

will contribute to long term sustainability. Environmental restoration of aquatic ecosystems and acquisition of lands for public use potentially enhance recreation aesthetics and use and also may lead to habitat and water quality improvements. Increased barge traffic or heavily concentrated recreational activity may contribute conflicts that detract from river recreation and even present safety hazards. CSOs and other nonpoint sources of pollution also can detract from river recreation and cause public health concerns. Counterbalancing these RFFAs are efforts such as the ORSANCO monitoring program, which assesses the river's water quality and helps warn of conditions that may degrade the environment and recreation experience.

9.11 SUMMARY AND CONCLUSIONS

Currently, the Ohio River is a popular setting for a broad spectrum of recreational activities. People living in counties adjacent to the river tend to view this resource as an important contributor to their quality of life and a significant portion of their recreational activity is oriented to the river. In urban areas, interests in the river have contributed to the provision of a wider range of opportunities, including riverfront parks and landings, large marinas, special events, and riverfront dining, shopping, and related entertainments. Almost every large and small community along the river provides some type of facility and event oriented to the river. Urban, small town, and rural settings along the river also serve as regional recreation and tourism destinations.

Events that draw large crowds and activities with large numbers participating attract a lot of attention, but solitude and quiet relaxation are some of the most important values associated with recreation on the Ohio River. People who look to the river for their recreation speak often of 'enjoying back-to-nature settings,' 'relaxing in quiet, uncrowded areas,' and 'scenic qualities, the beauty of the river.' These values are important to people participating in all types of activities, such as riverfront dining and sightseeing, hiking, biking, fishing, or just relaxing. People living in urban areas especially appear to value the river as a convenient way to escape and relax.

Recreational activities on the Ohio River have grown steadily since the early 1950s. Improved water quality during a time of economic prosperity appears to have been the principal contributor to past and recent growth trends. Water quality, accessibility, maintenance of recreation facilities, and an expanding selection of recreation choices are the primary factors affecting current trends in recreational activity.

There appear to be no significant impediments to continued growth of recreation on the Ohio River. People are generally willing to accept high levels of crowding on the busier urban pools, while more rural pools offer plenty of room for activities in a more natural setting. People using the river tend to be tolerant of others who recreate there and confident that reasonable enforcement of common sense rules can address most problems. People using the river also tend to accept the present level of commercial navigation activity and do not view barge traffic as posing a significant threat to their enjoyment or safety. As reported in the aquatic resources chapters, it appears likely that water quality in the Ohio River will continue to improve.

People who recreate on the river generally plan to continue doing so or to increase their activity in the foreseeable future. Existing parks and access facilities along the urban

pools are heavily used and new facilities are readily discovered and utilized. However, access points and other resources in some rural areas appear to be less crowded. A variety of public agencies and private organizations are actively engaged in development of new riverfront parks, greenways, trailways, boating access, and mixed use urban riverfront projects.

The principles of adaptive management can be applied to minimize potential long-term threats to the sustainability of recreation on the Ohio River. Elements of planning, monitoring, and early action before problems become critical can help avoid undesirable consequences. The greatest efforts in this respect should focus on protecting the natural resources that make the Ohio River so attractive to recreational interests. These include water quality, productive fisheries, healthy riparian habitats, scenic vistas, and opportunities for quiet relaxation in both rural and urban settings. In this context, embayments and wetlands should be monitored most closely, as these constitute limited resources along the Ohio River that are subject to competing pressures for use. In particular, embayments can provide important fishery, avian, water quality, and floodplain functionality benefits and are a popular setting for fishing, boating, swimming, waterfront parks, and other outdoor activities. They are also highly desired as sites for marinas, camping, casino resorts, and other developments that can severely degrade their resource functionality values.

Based upon the above-described actions and effects, the tiers of indicators, and the ES categories, the ES of recreation for the Ohio River mainstem can be characterized and depicted in **Figure 9-12** as follows:

- In the time period prior to 1920, and continuing up to about 1970, recreation on the Ohio River occurred in a degraded environment due to largely untreated and uncontrolled pollution discharges from growing municipalities, mining activity, and various types of industries and land uses along the river. Although the river continued to be used for recreation during this period, the overall ES was "marginally sustainable" and may have been "not sustainable" for the worst years of pollution. However, recreation information from the worst decades of pollution is limited as that time period coincided with the Great Depression, World War II, and the post-war period shortly thereafter, when leisure time and financial resources were limited.

- At the present time, recreation on the Ohio River is currently in a "sustainable" condition due in large measure to water quality improvements related to ORSANCO programs and requirements of the Federal Water Pollution Control Act (and the amended Clean Water Act). Water quality improvements, combined with increased economic prosperity, have increased demand for and stimulated development of marinas, ramps, and other recreation facilities along the river. The recent era of more integrated riverfront planning also has addressed recreation needs and has increased opportunities for an expanded spectrum of recreational choices.

- Regarding the future, it is expected that community planning and development of recreation facilities, further water quality improvements, especially in stormwater and CSO management, and habitat protection and restoration efforts will continue

to enhance recreation experiences. Socioeconomic projections for a stable or slowly growing population and continued improving standard of living would be expected to result in continued growth of demand for recreational opportunity. Consequently, the future ES is classified as "sustainable." Although the perception exists that increased participation could lead to overcrowding and competition for limited resources, it does not currently seem to be an overriding influence affecting people's decisions to participate in river-related activities.

FIGURE 9-12
ES of Recreational Resources

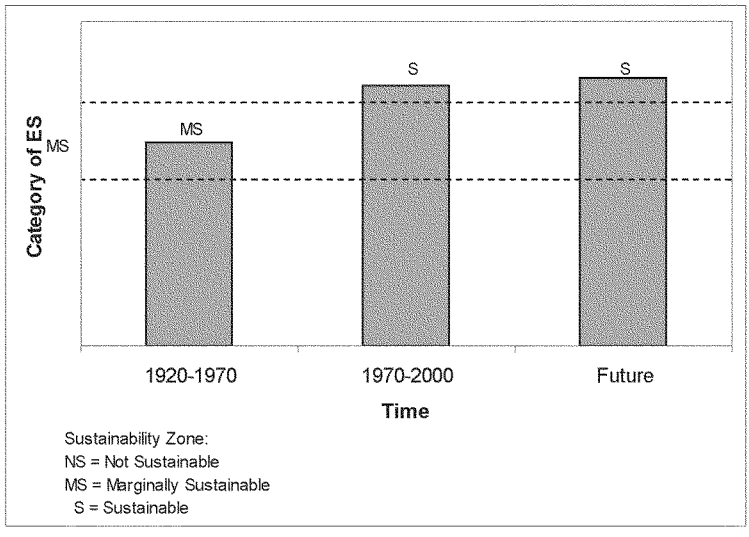


TABLE 9-9
AES Tiers for Actions Causing Recreation Effects Related to Opportunity and Accessibility

Examples of Actions Impacting Recreation Sustainability	Quantitative Measures Of Recreation Resource Factors	Composite Measures of Recreation Resource Factors	Composite Indicators of Recreation Sustainability
RFFAs include: • New locks, lock extension, replacement or rehabilitation • L/D O & M • Pool maintenance • Development or expansion of fleeting areas • Port and terminal development • Construction and maintenance of recreation facilities • Marina development	• Census counts of income, education, employment, other indicators of recreation opportunity or demand. • Survey of recreation activity, preferences, and demographics. • Ramp/marina and Fleeting area counts from Navcharts • Survey questions addressing accessibility • Focus Interviews • Topics from past-present history of recreational activities.	• Census and BEA calculations of household and per capita incomes, employment levels by SIC code. • Survey trend questions – future recreation demand and future effects of accessibility issues. • Focus interviews re future demand, direction, effects of accessibility issues. • Ramp/marina and fleeting area trends	• Projections based on fertility, mortality, immigration, labor force participation, and growth of national productivity. • "Most congested pools" as case studies for future crowding, space management issues (Markland, EDM, McAlpine). • Busiest commercial pools (lower river, also Markland & McAlpine). • Interpretation of survey & focus group findings (look at answers from urban, PA groups).

TABLE 9-10
AES Tiers for Actions Causing Recreation Effects Related to Quality of Experience

Examples of Actions Impacting Recreation Sustainability	Quantitative Measures Of Recreation Resource Factors	Composite Measures of Recreation Resource Factors	Composite Indicators of Recreation Sustainability
RFFAs include: • Increased barge traffic • Environmental restoration of aquatic habitats • Public lands acquisition and management • Stormwater discharges • Combined sewer overflows • ORSANCO monitoring programs	• Survey & focus group interviews. • Topics from past-present history of recreational activities.	• Trends – Inferred from survey & focus group interviews, factors influencing future activities.	• Interest/support for publicly subsidized recreation infrastructure: - Parks, trails, boating access, etc. - Riverfront developments-recreation features integrated with other entertainment, dining, shopping, etc. - Protection/enhancement of 'recreation environment' e.g., Ohio River Islands National Wildlife Refuge, other protections of open space, forested bluffs, viewscapes, aquatic/riparian resources, water quality.

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Chapter 10
TRANSPORATION AND TRAFFIC EFFECTS

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10.2 DEFINITION OF RIVER-RELATED TRANSPORTATION AND TRAFFIC

Transportation and traffic, as defined for the Ohio River Mainstem System Study (ORMSS), concerns the conveyance of goods and people along the Ohio River mainstem and the associated traffic activities. Transportation and traffic, consequently, considers the Ohio River navigation system, shipping volumes, shipping modes, and commodities shipped, as well as intermodal transportation facilities and connections. Intermodality focuses on how individual transportation modes can be integrated into a seamless, sustainable system.

Numerous business and economic forces influence population growth or loss and related economic changes along the Ohio River mainstem and, in turn, influence

transportation and traffic. Market forces and economic factors also influence the navigation system. Consistency and predictability in operation of the navigation system are keys to efficient, cost-effective transportation on the Ohio River mainstem.

10.3 OBJECTIVES AND SCOPE OF THE TRANSPORTATION AND TRAFFIC STUDY

10.3.1 Objectives

This chapter assesses the system-wide cumulative transportation and traffic effects of all likely major navigation improvements along the mainstem of the Ohio River from 2000 - 2070. Transportation and traffic impacts that are directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and Reasonably Foreseeable Future Actions (RFFAs) by the US Army Corps of Engineers (Corps) and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFAs. These future actions include major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, actions by non-governmental entities, and predictions of general economic expansion and development.

The results of the Cumulative Effects Assessment (CEA) are intended to contribute to two topics of subsequent public debate: (1) whether the impacts of the RFFAs constitute acceptable outcomes for the affected resources and (2) how the proposed navigation improvements contribute to those outcomes.

10.3.2 Geographic Scope

The primary geographic focus for transportation and traffic impacts includes those areas most directly impacted by operation and maintenance of the navigation system, that is, the Ohio River itself and associated ports, terminals, and intermodal sites located in adjacent riparian areas. The more comprehensive intermodal perspective of the study area, however, includes railways and highways radiating out into the larger Ohio River basin.

10.3.3 Time Frame

The established time frame for this project is 1920 to 2070. The earlier date approximates the initiation of modern Corps lock and dam construction activities on the Ohio River. The latter date approximates the end of the 60-year planning horizon encompassed by ORMSS.

10.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during Summer 2001 in communities along the Ohio River. The meetings created opportunities for the public, state and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through

comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. More detailed discussions of the scoping meetings are presented in Exhibits A and B of this CEA.

The meetings were attended by 185 persons, and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted.

Transportation and traffic was a major focus of the meetings with more than 60 individual comments on it. **Table 10-1** presents comments that directly and indirectly addressed transportation and traffic.

TABLE 10-1
Comments from Public Scoping Meetings

Direct Comments on Transportation and Traffic	Relevance to Transportation & Traffic	Total Comments
Study may overemphasize transportation and river commerce	Other aspects of study may not be considered adequately	1
Application of Ohio River Navigation Investment Model to ORMSS	Integration of model with ORMSS is needed	1
Relationship between ORMSS and completion of Olmsted L/D	Timing and integration of the study and the project	1
Integration with ORMSS with the U.S. DOT Marine Transportation Study	Relationship between the two studies	1
How ORMSS study will affect Greenup L/D upgrade	Clarification of interaction between the study and the project	1
Inclusion of no-action alternative in ORMSS	Need to discuss impacts of no navigation improvements	1
Loss of shoreline trees and river property caused by barge activity	Frequently expressed concern related to barge traffic and "toeing in"	7
Reliability of barge traffic forecasts	Actual need for lock expansions	5
Failure of barges to stay in designated shipping lanes	Environmental impacts and safety issues	2
Changes in shipping demand as low sulfur coal reserves near depletion in next 25 years	Effects on traffic forecasts	1
Why USACE expects only 1% increase in barge traffic, while a 3% increase in gross domestic product is expected	Discrepancy between traffic and economic forecasts	1
Navigation structures presently not keeping pace with traffic demands	Potential inability of navigation system to meet future needs	3
Clarification of scheduling and frequency of lock closures	Assessment of current conditions	1
View of navigation improvements as benefiting only shipping industry	Concern about general need for improvement	1
Why economic forecast model is based on use of auxiliary locks	Clarification of auxiliary locks use	1
Has ORNIM (navigation investment model) been run on the system	Validity of ORNIM	1

Direct Comments on Transportation and Traffic	Relevance to Transportation & Traffic	Total Comments
Support expressed for value and maintenance of OR navigation system	Importance of system to transportation and traffic	3
Importance of maintaining shipping channel	Importance for traffic flow and minimizing environmental impacts	2
Bank undercutting and failure caused by increased barge traffic, queuing and wave action	Frequently voiced environmental impacts of transportation and traffic	7
Enhancement of river transportation capabilities through corresponding development/improvement of intermodal transportation facilities	Relationship between river transportation and other modes of transportation	2
Need for long-range coordination with FHWA, state and local transportation agencies	Coordination of intermodal transportation	1
Need to integrate navigation with other transportation modes	Importance of intermodal transportation	2
Concern about ancillary movement of goods and services in emergencies, e.g., bridge destruction	Preparedness for emergency situations	1
Use of AWO and DINAMO to notify towing industry of public meetings	Concern that relevant parties were notified	1
Interest in including a vision of the river for the year 2070	Projection of transportation and traffic in 2070	1
Accuracy of models for predicting population growth and development	Impacts of such growth on transportation and traffic	1
Relationship between CEA and SIP products schedules	Timing and integration of the two studies	1
Need to consider most operations of commercial navigation system as direct USACE actions	Identification of USACE responsibilities	1
ORMSS schedule possibly lagging behind future navigation needs	Potential inability of navigation system to meet future needs	5
Status of funding for J.T. Myers L/D	Status of this specific navigation improvement	1
Assessment and documentation of Olmsted construction	Status of this specific navigation improvement	1
Current cost estimates on lock extensions at Myers and Green L/Ds	Cost of extensions in today's dollars	1
Effects of Greenup L/D improvements on barge queuing	Impacts of improvements in facilitating traffic movement	1
Overall effects of navigation structures and activities on groundwater levels	Impacts of pool levels on groundwater levels	1
Increase in barge loading/unloading facilities limiting fishing access from shore	Potential conflict between transportation and recreation	1
Need for fish habitat improvements, including fish passages around L/Ds	Interference of navigation system with fish migration	2
Stress and disruption of waterfowl migratory patterns caused by barge traffic	Interference of navigation system with waterfowl migration	1
Estimated number of officers that enforce shipping regulations along OR	Capacity for enforcement affecting existing transportation and traffic	1
Need for USACE to encourage uniformity in navigation charts along length of OR	Addresses safety and communication issues	1

10.5 INDICATORS OF ENVIRONMENTAL SUSTAINABILITY

Indicators of Environmental Sustainability (ES), which vary by Valued Environmental Component (VEC), generally provide benchmarks for measuring CEs on a given resource. Sustainable transportation considers transportation systems, policies, and technologies and is inextricably linked to socioeconomics and the environment. The following definition, adapted from the Centre for Sustainable Transportation in Ontario (http://www/cstctd.org/CSTaboutus.htm), applies to transportation along the Ohio River mainstem:

A sustainable transportation system:

- Allows the basic needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations;
- Is affordable, operates efficiently, connects with other transportation modes, and supports a vibrant economy; and
- Limits emissions and waste within the environment's capacity to handle them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components and minimizes the use of land and the production of noise.

Many transportation indicators are time series, which compare the same data at different times and, consequently, can show movement toward or away from sustainable conditions. Environmental indicators relevant for this study include:

- Barge tonnage passing through each lock over time
- Annual barge tonnage with origin and destination within the Ohio River navigation system
- Annual barge tonnage with origin in the system but moved out of the system
- Annual barge tonnage with origin outside the system but moved into the system
- Percentages of different commodities transported along the river over time
- Numbers of terminals and intermodal transfer facilities over time
- Average queuing times for barge traffic at locks over time
- Capacity and condition of rail and highway links in the study area and
- Amount and types of fuel used by tows over time.

In addition to providing measures of sustainability overall, these indicators can reveal the effects of governmental and business policies and practices. Further, they can help shape new policies and practices.

10.6 LAWS, REGULATIONS, ORDINANCES, AND PROGRAMS

One of the most significant legislative acts related to Corps' regulatory activities and river transportation was enacted more than a century ago in 1899 when the Rivers and Harbors Appropriation Act was passed. Since then, the act has been amended several times, but many key sections of the 1899 act remain relevant to river transportation and

traffic in the 21st century, including the authority of the Corps to issue permits under the act. The Water Resources Development Act, first enacted in 1976 and subsequently reauthorized several times, also has far-ranging implications for Corps' activities and includes general provisions that enlarge the Civil Works program's mission to include environmental protection in planning, designing, constructing, operating, and maintaining Corps' projects. During the 1980s, both the Harbor Maintenance Tax and Inland Waterways Trust Fund began to generate significant funds dedicated to maintaining and expanding the navigation system on the nation's inland waterways.

The latter third of the 20th century also witnessed the passage of several key environmental acts (e.g., NEPA, Clean Water Act, Oil Pollution Act, and others) that directly influence Corps activities. **Table 10-2** presents information on important federal regulations and established programs which influence transportation and traffic on the Ohio River.

TABLE 10-2
Laws, Regulations, Ordinances, And Programs Relevant to Transportation and Traffic

Law/Program	Key Components	Relevance to Transportation and Traffic
Rivers and Harbors Acts (U.S. Army Corps of Engineers)	• Address projects and activities in navigable waters and harbor and river improvements. • Section 7 authorizes promulgation of regulations for use of navigable waterways, including operations that provide channel improvements. • Section 10 of Rivers and Harbors Act (1899) relates to permits for physical obstructions to navigable U.S. waters.	Provides for improvements, maintenance and safety of ports and navigation channels.
Water Resources Development Acts (U.S. Army Corps of Engineers)	• Authorizes the study and/or implementation of various projects and programs to improve river and harbors, including several general environmental provisions. • WRDA of 1986 enacted the Harbor Maintenance Tax, paid by shippers, to cover costs of maintaining navigation channels. • Implements a cost-share formula between local ports and the federal government for improving harbors and channels.	Facilitates safe traffic movement through maintenance of ports and navigation channels.
Inland Waterways Revenue Act	• Created a diesel fuel tax to defray costs of lock and dam construction and major rehabilitation along major inland waterways. • WRDA of 1986 increased fuel tax to 20¢ /gal.	Provides a dedicated source of funding for navigation system expansion and maintenance.
Safe, Accountable, Flexible, Efficient Transportation Act: a	• Builds of the ISTEA and TEA-21 acts which promotes balanced, integrated and efficient approaches to	Emphasizes intermodal facilities and connections (e.g., between barge

Law/Program	Key Components	Relevance to Transportation and Traffic
Legacy for Users (SAFETEA-LU) (U.S. Department of Transportation)	transportation that connect various transportation modes. • PL 109-59, signed into law on August 10, 2005	transportation and highways or railways). Encourages flexibility to attempt new transportation solutions.
Clean Water Act (CWA) (U.S. Environmental Protection Agency)	• Establishes structure for regulating discharges of dredged or fill and pollution materials into U.S. waters and requires establishment of water quality standards. • Section 401 requires applicants proposing activity, which may result in discharge to U.S. waters, to obtain state certification of compliance with state water quality standards.	Applies to removal and disposal of materials dredged to maintain navigation channels or to expand or construct navigation structures.
Emergency Planning and Community Right-to Know Act (a.k.a. as SARA Title III) (USEPA and state and local emergency response agencies)	• Requires emergency planning and preparedness at state and local levels. • Section 304 establishes spill reporting requirements for facilities that release extremely hazardous substances.	Requires commercial shipping companies to prepare emergency response plans and submit records on hazardous chemicals they are transporting.
Hazardous Materials Transportation Act (U.S. Department of Transportation)	• Governs the transportation of hazardous materials, including, but not limited to, solvents, asbestos, PCBs, paints, pesticides, hazardous wastes, etc,	Requires commercial shipping companies to comply with DOT requirements for documentation, labeling, and all other regulations associated with safe transport of hazardous materials.
National Environmental Policy Act (NEPA) (Council on Environ-mental Quality and other agencies)	• Requires preparation of environmental impact statements for new construction projects by private and governmental agencies • Includes federal government's responsibility to prevent environmental degradation.	Applies to all projects receiving federal funding, including construction of navigation structures and port developments.
Pollution Prevention Act (U.S. Environmental Protection Agency)	• Establishes the policy of pollution prevention, reduction and recycling in an environmentally safe manner whenever feasible • Requires facilities filing annual toxic chemical release forms to also file a toxic source reduction and recycling report	Protects public safety by requiring pollution reduction or recycling of hazardous substances, toxic chemicals and toxic and radiological wastes at their sources
Oil Pollution Act (U.S. Environmental Protection Agency and U.S. Coast Guard)	• Strengthens governmental ability to prevent & respond to catastrophic oil spills • Requires oil storage facilities and vessels to submit plans detailing how they will respond to large discharges	Protects drinking water supplies and natural resources from pollution & damage from oil spills.
Spill Response	• Includes emergency response	Minimizes adverse impacts

Law/Program	Key Components	Relevance to Transportation and Traffic
(ORSANCO and U.S. Coast Guard)	activities for river-related spills and accidental discharges and is related to the Oil Pollution Act and Section 301 of the Clean Water Act.	of spills and discharges on mussels and other aquatic life and on water quality
Abandoned Shipwreck Act (National Park Service)	• Provides federal protection for any shipwreck that meets the criteria for eligibility for inclusion on the National Register of Historic Places.	Prohibits disposal of dredged or other material in or near historic shipwrecks.
Executive Order 13274	• Enhances environmental stewardship and streamlines decision-making process for major transportation projects. • Requires DOT to prioritize projects and establishes interagency task force to coordinate decision-making across federal agencies.	Applies to transportation projects on inland waterways.

10.7 PAST TO CURRENT BASELINE CONDITIONS

10.7.1 Transportation Patterns during the 19th and Early 20th Century

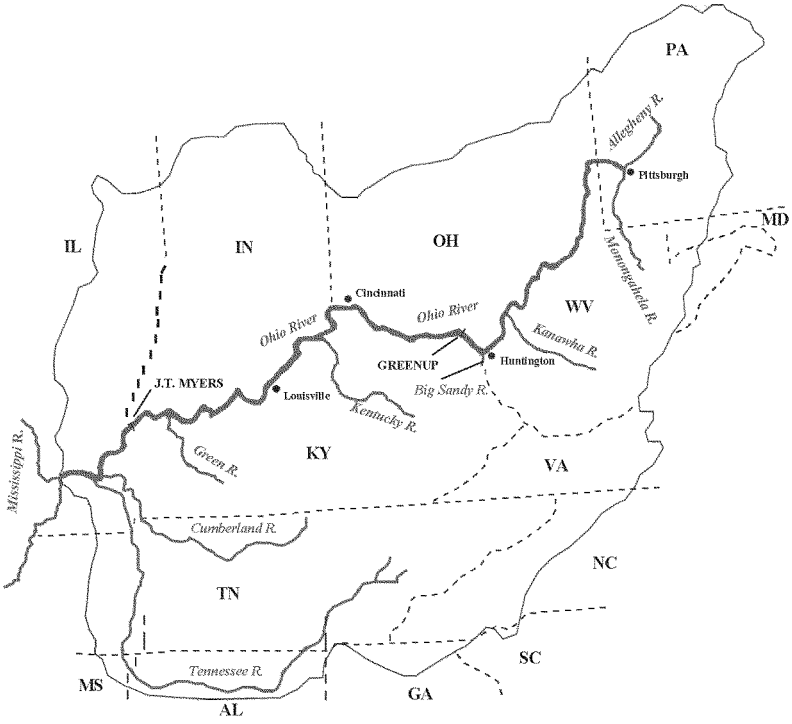
The Ohio River is an important artery of the nation's inland waterway system, providing for commercial navigation in the eastern third of the country. The entire Ohio River navigation system consists of the Ohio mainstem and navigable portions of eight tributaries, the Allegheny, Monongahela, Kanawha, Big Sandy, Kentucky, Green, Cumberland and Tennessee rivers **(Figure 10-1)**. The mainstem serves as a collector of system traffic for distribution points within and outside the Ohio basin. Through interconnections with the Mississippi River and its tributaries, the Ohio River navigation system also has access to Midwestern states and deep-draft ports on the Great Lakes and the Gulf Coast. While this chapter focuses primarily on water transportation, it also considers the intermodal linkages that extend the influence of commerce on the Ohio mainstem far beyond the Ohio basin.

Bigham (1998) refers to the Ohio mainstem as the nation's first interstate highway, bringing goods and people to the first western frontier. During the early decades of settlement, the Ohio River provided the primary corridor of transportation, both for immigration of new settlers and for the shipment of regional products; consequently, initial settlements within the region tended to cluster along the Ohio River. Certain port development opportunities related to transportation, such as the Falls of the Ohio at Louisville or location of the national road crossing at Wheeling, directly contributed to the location and expansion of towns along the Ohio. Some early riverfront settlements subsequently prospered as hubs or service centers to interior regions reached overland by horse and wagon. This was an early example of intermodal transportation.

The earliest flatboats and keelboats mostly provided one-way transport downstream, necessitating shipment of produce through New Orleans and coastal shipping to reach eastern markets. The arrival of steamboats around 1815 permitted two-way traffic and greatly reduced travel times (Carlisle & Mulligan 2001). Development of the Ohio River

in the 1800s included the removal of snags, completion of the initial canal and locks around the Falls of the Ohio in 1833, and completion of the first wicket dam at Davis Island, near Pittsburgh in 1885. However, the Ohio River remained largely unimproved prior to the 1920s. The ability to move commodities, consequently, was constrained by the seasonal availability of high water flows sufficient to support navigation.

Figure 10-1
Ohio River Basin



Inland canals provided the first significant alternative or supplement to river transport, beginning in 1825 with completion of the Erie Canal from Buffalo to New York City. Important canals in the Ohio River Valley included the Ohio & Erie from Lake Erie to Portsmouth, OH; the Pennsylvania Mainline from Pittsburgh to Philadelphia; and the Pennsylvania & Ohio from Pittsburgh to the Mahoning River Valley in Ohio (Carlisle & Mulligan 2001). By 1830, approximately 3,000 miles of canals operated in the United States. Canals provided nearly year-round transportation and the ability to ship products more directly to eastern markets instead of overland from Upper Ohio, Allegheny, or Monongahela ports. On balance, canal development probably supplemented river traffic more than it competed with or replaced river traffic. Steamboats hauled goods to canal terminals on the Ohio River, creating another early form of multimodality.

The expansion of railroads provided a far more significant level of competition to river transport and quickly became the primary means of commercial transportation in the

region. Railroads provided true year-round transport capabilities, greatly reduced transport times, and could be quickly built to serve any point-to-point business opportunity. The first railroad in the Middle Ohio River Valley was completed in the 1840s, connecting Lake Erie with the Ohio River. By 1850, 242 miles of track were completed in the Middle Ohio River Valley. By 1855, this number exploded to 1,247 miles and virtually saturated rail transport opportunities in the region. Rail mileage in the region grew only an additional 80 miles by 1860 (Carlisle & Mulligan 2001). Railroads almost immediately rendered canals obsolete. Track sometimes was laid beside or over the abandoned canals.

Commercial river transport also declined at a slow but steady pace in competition with railroads. The year-round operability of rails had a distinct advantage over the seasonal limitation of steamboats. Inland cities with good rail connections grew substantially. To a large degree, the early river communities along the Ohio River either prospered or perished with the railroads, depending on their ability to attract rail service. Subsequently, further prosperity came to most towns able to establish railroad bridges across the Ohio River.

The latter decades of the 19th century and early decades of the 20th century included a period of heavy industrial development along the middle and upper Ohio River. This development centered on the iron and steel industry in Pittsburgh, with its convergence of raw materials, coal, river, and rail and river transportation to move materials and products into and out of the region.

Concisely stated, the Ohio River stimulated a variety of transportation and technological strategies that pushed expansion westward and added to the nation's overall prosperity (Bigham 1998).

10.7.2 Transportation Patterns from the 1920s to the Present

Construction of the system of wicket locks and dams ultimately revitalized the Ohio River as a major transportation corridor, although wartime activities would later contribute to its expansion. Following construction of the first project in 1885 at Davis Island, the next lock and dam project was not finished until 1904. Surprisingly, initial construction of the dams was opposed by some members of the barge industry, who feared that breaking up multiple barge tows for passage through the locks would make river freight impractical (McVarnish 2001). However, completion of the initial projects proved the advantages of this navigation development and sentiment began to change to favor canalization. After the Davis Island Lock was in operation, an unexpected flood in July 1888 particularly gave momentum to downstream canalization. One hundred coal barges sank along the Ohio River, but no barge in the harbor behind Davis Island was lost. Furthermore, industry located along the Davis Island pool benefited from a more reliable water supply. Fears that the pool would be a stagnant breeding ground for disease proved unfounded. Instead, sewage and other obnoxious effluents which had formerly rotted along the shoreline during low water periods were washed away.

Both rivermen and industrialists urged the extension of canalization downriver (Johnson 1977; cited in McVarnish 2001). Six lock and dam projects were completed between 1904 and 1910, 23 were completed between 1911 and 1920, and the entire system of more than 50 lock and wicket dam projects was completed by 1929. The original design

for a navigation depth of six feet was modified in 1910 to provide the nine-foot depth required for coal barges that had begun operating on the river by 1900.

As construction of the navigation system continued, however, river traffic declined, primarily because of rail transportation. In 1917, cargo carried on the river reached a low of about 4.6 million tons, a nadir caused largely by the decline of coal shipments from Pittsburgh to New Orleans, as coal was diverted to steel plants in the Upper Ohio Valley. The turning point came as World War I continued and wartime shipping overburdened the country's land transportation system. By 1920, cargo volume on the Ohio River had risen to almost 9.4 million tons, a total that increased further to 10.8 million tons in 1924), 16 million tons by 1925, and 22.3 million tons by 1930 (Froggett 1926a & b, Robinson 1983, and USACE-ORD 1979; cited in McVarnish 2001). Where traffic once consisted primarily of coal and steel products moving downstream, new products were being added as the century progressed. Freight soon included petroleum and its products, iron and steel, dry and liquid chemicals, grain, cement, and a variety of other items (Gaum 1970, cited in McVarnish 2001).

Commerce on the river grew steadily through the 1930s and 1940s while development of diesel towboats and larger barges created opportunities for larger scale, more efficient movement of commodities. Designed for about 15 million tons of commerce annually, the old locks and dams handled more than 70 million tons in 1954; in addition, traffic moving upstream on the Ohio had nearly equaled that moving downstream. Plans to improve system efficiency and accommodate the larger tugs and barges called for reducing the number of dams by building high-lift projects with larger capacity locks. The final plan, approved in 1954, envisioned a total of 19 high-lift projects with dual lock chambers. It began with the construction of Greenup and New Cumberland L&Ds, although construction of Emsworth, Dashields, Montgomery and Gallipolis L&Ds during the 1930s had already replaced some old locks and wicket dams on the upper river. Implementation of the current phase of lock extensions actually overlaps completion of the mid-century modernization program. Olmsted Locks and Dam, under construction at RM 964.4 will complete the 1954 modernization plan and replace old L&D 52 and 53. Upon Olmsted's completion, there will be 19 lock and dam projects along the Ohio River mainstem, as envisioned almost 50 years ago. **Table 10-3** provides a synopsis of the key dates in the historical development of navigation on the Ohio River.

TABLE 10-3
Chronology of Navigation Development - Ohio River

1811	The NEW ORLEANS is the first steamboat to navigate the Ohio.
1824	First Federal funding for river improvements; removal of snags and clearing sand bars
1830	Completion of Louisville and Portland Canal
1874	Beacons, buoys, and daymarks put into use on the River; Corps given jurisdiction at Falls of Ohio.

1885 Davis Island Lock and Dam completed near Pittsburgh.

1929 Series of 51 locks and wicket dams completed.

1954 Corps begins modernization program replacing movable dams with stationary high-lift dams.

1992 Construction begins on Olmsted Locks and Dam, last project in 1950's modernization program.

SOURCE: http://www.lrl.usace.army.mil/ld98/HISTORY.HTM

During the 20th century era of sustained urban growth, the demands of industrial and commercial development outpaced the availability of land within some of the rapidly growing riverfront urban centers. Within the Huntington and Louisville Districts, for example, a series of levee and floodwall projects were completed during the 1930s and 1940s to secure more land for development as well as to protect existing properties against flooding. Rapidly growing cities also expanded beyond the river floodplain to higher ground, utilizing mass transit (e.g., light rail and bus) and automobiles to connect their expanding fringes with urban riverfront cores.

The availability of reliable, inexpensive electric power contributed significantly to the industrial and commercial growth of the Ohio Valley. Construction of the wicket dams contributed to bulk transport of the region's coal and provided stable pool elevations for construction of coal fired utilities on the Ohio River and its primary tributaries. Over the years, economies of scale have favored development of the very large power plants that are now a part of the river landscape of the Ohio Valley.

10.7.3 Current Conditions and Operation of the Navigation System and Transportation

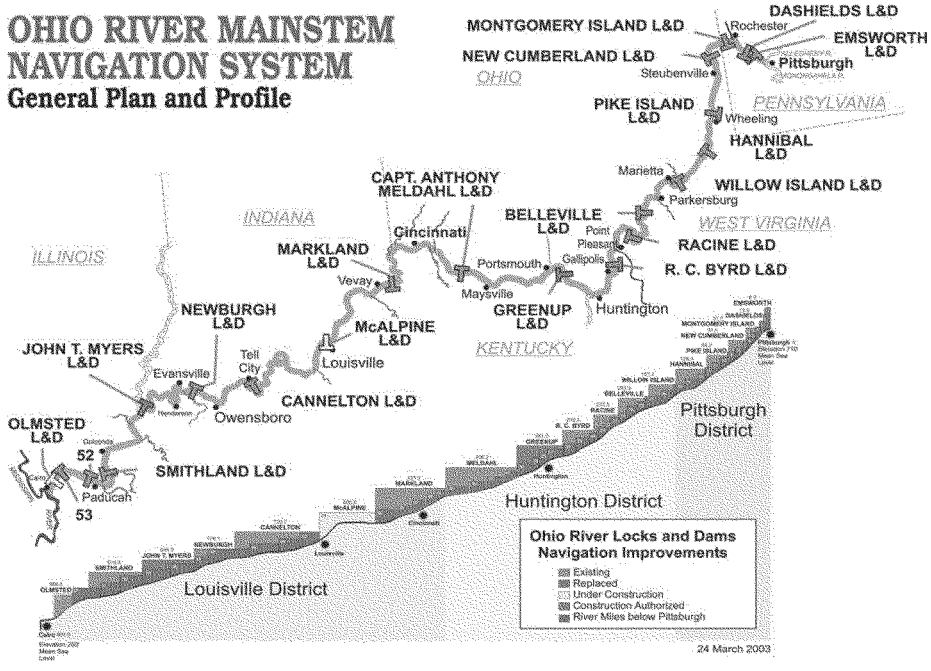
Existing navigation conditions, as described in the J.T. Myers and Greenup Lock Improvements report (USACE 2000) are presented below:

- The current geometry of the river, as improved by the higher pool levels of the modernized dam system, generally provides for safe navigation of commercial tows as long as 1200' long x 108' wide. Over the decades, barges have increased in size. A typical large jumbo-hopper-barge tow consists of fifteen 195' x 35' barges, plus a towboat of varying dimensions, resulting in a tow of about 1170' x 105'. Occasionally, tows on the lowermost reaches of the Ohio, below Smithland L&D, operate in a double-wide configuration of 30 barges (5 long x 6 wide), typical of the larger tows on the lower Mississippi River. During winter months, these six barge-wide tows can navigate over the navigable wickets of Dams 52 and 53 (and the wickets at the new Olmsted Dam when it opens). Such tows cannot navigate these reaches during the drier months, when they must use the locks at L&D 52 and 53. **Figure 10-2** shows the sequence of navigation structures and the river profile.

- The 60+ year-old upper three structures (Emsworth, Dashields, and Montgomery L&Ds) are just downstream of Pittsburgh PA. These three locks each have one larger 600'x110' main chamber and a 360'x 56' auxiliary

chamber. Fifteen-barge tows must be processed in two sections, called "double-cuts," through the main chamber, while tow sizes are limited to five-cuts in the small auxiliary chamber. The age of these structures, combined with the inefficiently-small lock sizes, has raised major concerns. Not only is age important because of its effect on reliability, but also because of the construction methods and design practices used in the 1910s to 1930s when they were constructed. (Frechione & Walker 2003).

FIGURE 10-2



In terms of age and size, the locks and dam facilities may be classified into 3 broad groups:

- The 13 modernized lock and dam structures constructed between 1954 and 1979, plus Byrd L&D, which has new locks completed in 1995. This includes all the sequential locks from New Cumberland downstream to J.T.Myers, a distance of 791.6 miles. Each of the locks has a 1200'x110' main lock chamber and a 600'x 110'auxiliary chamber. The 1200' long main chamber allows 15-barge tows to lock through in a single operation, while smaller tows or other vessels usually use the auxiliary chambers. These newer locks and dams are spaced about 60 miles apart, on average, and replaced about 40 lower-lift dams built at the turn of the 20th century.

- Locks and dams with dual 1200'x110' lock chambers include Smithland (placed in operation in 1980), McAlpine (chamber expansion from 600' to

1200' completed in 2002) and Olmsted (under construction). WRDA 2000 authorized 600' auxiliary lock extensions at J.T. Myers and Greenup L/D that are both currently in design phase.

Specifications for the existing lock and dam projects are summarized in **Table 10-4**.

TABLE 10-4
Current Ohio River Lock Specifications

Lock & Dam	River Mile	Year Operational			Year Rehabilitated			Chamber Sizes	
Project Name	(downstream of Pittsburgh)	Main	Aux.	Dam	Main	Aux.	Dam	Main	Aux.
Emsworth	6.2	1921	1921	1922	1984	1984	1984	600x110	360x56
Dashields	13.3	1929	1929	1929	1990	1990	1990	600x110	360x56
Montgomery	31.7	1936	1936	1936	1989	1989	1989	600x110	360x56
North Cumberland	54.4	1956	1959	1961				1200x110	600x110
Pike Island	84.2	1963	1963	1965				1200x110	600x110
Hannibal	126.4	1972	1972	1975				1200x110	600x110
Willow Island	162.4	1972	1972	1973				1200x110	600x110
Belleville	203.9	1968	1968	1969				1200x110	600x110
Racine	237.5	1967	1967	1970				1200x110	600x110
R.C. Byrd	279.2	1993	1993	1937			2000+	1200x110	600x110
Greenup	341	1959	1959	1962				1200x110	600x110
Meldahl	436.2	1962	1962	1964				1200x110	600x110
Markland	531.5	1959	1959	1964				1200x110	600x110
McAlpine	606.8	1961	1921	1964		1965		1200x110	1200x110
Cannelton	720.7	1971	1971	1971				1200x110	600x110
Newburgh	776.1	1975	1975	1975				1200x110	600x110
J.T. Myers	846	1975	1975	1975				1200x110	600x110
Smithland	918.5	1979	1979	1979				1200x110	1200x110
L&D No. 52*	938.9	1969	1928	1929	1983	1983	1984	1200x110	600x110
L&D No. 53*	962.6	1980	1929	1929	1983	1982	1984	1200x110	600x110
***Notes:** Olmsted L&D (now under construction near L&D53) will replace both L&D52 and L&D53. Olmsted will have dual 1200' x 110' chambers, with completion projected for 2010.									
Source: J.T. Myers & Greenup Lock Improvements – Economics Appendix (2000).									

The Corps currently operates the Ohio River projects on a first-come/first serve basis during normal periods. The Corps also provides "Lock Status Reports" on the Internet that give real-time information on the status of traffic and lock operations on the navigation system (USACE –Pittsburgh District 2003). The normal procedures for operating the navigation projects follow:

1) tows are processed on a first-come/first-serve basis;

2) the main chamber is used to lock most tows;
3) the auxiliary chamber is primarily used to lock recreational craft and lightboats (towboats without barges);
4) tows are restricted to one-cut lockage operations (no splitting of tows) in the main chamber except for the upper three projects, which allow two-cut lockage operations (splitting tows into two sections) because of the small size of the main chamber;
5) all craft are restricted to one-cut lockage operations through the auxiliary chamber;
6) locks are operational nearly 100 percent of the time during the year (with a low number of weather related closures) (USACE -Pittsburgh District 2003).

During 2000, over eight of every ten tows locked through the main chamber at the projects. The main chamber is often used even when the tow could one-cut through the auxiliary chamber. The main chamber is preferred for several reasons, including better approach conditions and the lock operators' greater familiarity and comfort with operating the main chambers. Traffic and delays by chamber are included in **Table 10-5** which indicates the average delay per tow under normal operation at the main chambers was 0.94 hours (56.4 minutes). The average delay at the auxiliary locks was 0.63 hours per tow (37.8 minutes), but at 14 of 19 projects it was 6.6 minutes or less. Low levels of delays at the auxiliary locks are the norm in the absence of main chamber closures.

Significant delays at Ohio River locks and dams are linked to lock closures rather than to spikes in hourly, daily, or monthly arrivals (USACE - Pittsburgh District 2003). Lock closures are: (1) nearly always scheduled, (2) last from 30 to 60 days, and (3) occur on a five- to ten-year maintenance cycle. Navigation notices, published about six months before lock closures, provide details on operating procedures and expected delays, and give industries time to adapt their operations to reduce closure effects. In general, highest delays occur at the three uppermost projects — Emsworth, Dashields, and Montgomery L/D—due primarily to the extremely small size of the auxiliary locks and at the eight lowermost L/D, due to higher traffic levels (USACE - Pittsburgh District 2003).

Normal operating policies change when lock closures result in significant queues and delays. First, two-cut lockages are allowed at the projects with 600'auxiliary chambers, because this allows the tow size to remain the same over the vessel trip. At the upper three projects, five-cut lockages are allowed because of the much smaller size of the auxiliary locks, although even five-cut lockages are insufficient to lock a 15-barge tow. Second, during closure delays the first-come/first-serve policy is changed to "n up/ n down," a policy which processes multiple barges moving in one direction, followed by an equal number of tows moving in the opposite direction (Frechione & Walker 2003). The n up/n down policy (also called "sequential processing") and other measures to expedite tow movement during lock closures are discussed in the following section.

The towing industry makes adjustments to lock closures, particularly at locks where the longest delays occur. At all times, including closures, shippers attempt to minimize the time spent pushing empty barges by arranging shipments in both directions. The percent of loaded barges is higher at projects along the lower river, where opportunities for backhauls (loaded return trips) are greater than on the upper river, where one-way coal traffic is more dominant (USACE – Pittsburgh District 2003). Towing companies also try

to reduce the number of trips through locks with significant delays. In some cases, they dispatch additional equipment (e.g., "helper" boats) to assist with assembling barges above and below congestion points to expedite returning to normal delivery schedules as soon as a main chamber reopens.

TABLE 10-5
Traffic and Delays by Chamber – 2000

	Tows			Delays - Hrs/tow		
Project	**Main**	**Aux**	**Total**	**Main**	**Aux**	**Total**
Emsworth	3,876	1,123	4,999	0.84	0.08	0.66
Dashields	3,803	935	4,738	0.65	0.07	0.53
Montgomery	3,854	770	4,624	1.09	0.20	0.94
New Cumberland	3,269	1,078	4,347	0.32	0.05	0.25
Pike Island	3,193	1,571	4,764	0.33	2.65	1.10
Hannibal	3,894	586	4,480	0.28	0.03	0.25
Willow Island	3,609	474	4,083	0.47	0.03	0.42
Belleville	3,897	338	4,235	0.38	0.04	0.35
Racine	3,981	495	4,476	0.50	0.03	0.45
Gallipolis	4,461	621	5,082	0.75	0.04	0.66
Greenup	6,202	639	6,841	1.02	0.06	0.93
Meldahl	5,216	255	5,471	1.03	0.11	0.99
Markland	4,694	435	5,129	0.65	0.03	0.60
McAlpine	5,018	18	5,036	1.43	8.94	1.46
Cannelton	4,290	304	4,594	0.71	0.05	0.67
Newburg	5,094	698	5,792	0.52	0.05	0.46
Myers	5,359	599	5,958	0.83	3.48	1.09
Smithland	3,504	3,761	7,265	0.03	0.04	0.03
L/D 52	7,230	2,328	9,558	3.56	1.57	3.07
Total	84,444	17,028	101,472			
Average	4,444	896	5,341	0.94	0.63	0.89
Percent	83.2%	16.8%		88.0%	12.0%	
SOURCE: USACE – Pittsburgh District 2003						

Delays represent transportation inefficiencies that could possibly be reduced by more effective management of the navigation system rather than by costly construction efforts. A framework for formulating and evaluating alternatives to navigation problems, including those related to inland navigation, exists in the Corps' Planning Guidance Notebook (ER 1105-2-100). Regulations in the Notebook are general enough to allow substantial flexibility, but do have basic requirements, including that:

1) evaluations must be made within a system context,
2) project economics must be based on national economic benefits and costs, and
3) nonstructural alternatives must be evaluated along with structural alternatives.

The Corps is using a new tool, the Ohio River Navigation Investment Model (ORNIM) to identify and evaluate the structural and nonstructural alternatives that yield the optimal combination of capacity enhancement and nonstructural investments for the Ohio River system (Frechione & Walker 2003).

10.7.4 NONSTRUCTURAL TRAFFIC MANAGEMENT MEASURES

Nonstructural alternatives are used to facilitate tow passage through the locks and provide transportation efficiencies, particularly during unexpected lock chamber outages and planned lock closures for inspection and repairs, as well as during normal operations when two or more tows arrive simultaneously expecting lockage service. Nonstructural measures can be divided into two groups:

1) technical measures that increase capacity of the system of locks and dams and
2) demand management measures that provide the lowest cost to users who value the system most.

Technical measures seek to improve tow passage through locks during times of congestion when the first-come/first-serve policy is less effective than under normal operating conditions. In contrast, demand management measures seek to alter shipper behavior either by more closely aligning shipper costs with the true economic costs of using the navigation system or by educating users such that external costs are reflected in their prices. Demand management efforts do not directly increase lock throughput; instead they potentially decrease traffic delays by moving traffic away from congested shipping periods and locations.

Table 10-6 describes and compares the three main technical nonstructural measures currently in use on the Ohio River. All projects, except those with dual 1200'chambers, employ both sequential processing and helper boats during lock closures. Although time savings vary by project, the reduction in processing time per tow when these two measures are combined is about 125 minutes. Further, the combination of sequential processing and helper boats is estimated to be one-third more time effective than the use of tow haulage by itself (Frechione & Walker 2003). Additional nonstructural technical measures to further reduce delays are not apparent at present.

TABLE 10-6
Technical Nonstructural Measures that Increase System Capacity

Measure	How Measure Works	Effectiveness	Current Usage
Sequential tow processing (n-up/n-down)	Changes tow processing from first-come/first-serve to sequential processing of tows moving in the same direction. Allows tow to wait at the lock for processing rather than wait at the approach point several hundred feet distant.	Reduces approach time by about 15 minutes per tow and therefore increases efficiency of locks by reducing idle time.	Employed during lock closures at all projects with auxiliary chambers smaller than the main chamber.

Measure	How Measure Works	Effectiveness	Current Usage
Tow haulage systems to extract unpowered barges	When double lockages are required,: 1) Unpowered barges are cabled to a moveable tie-down unit, which moves along railroad tracks to pull barges out of the chamber. 2) The second set of barges, powered by a towboat, enter and lock through the chamber. 3) After the second lockage, the first and second cuts are assembled along the guidewall.	Estimated time savings per tow is one to two hours. The alternative of "double tripping" at smaller locks would require towboats to lock through with the first cut of barges, return through the same lock, then return with the second cut and reassemble all the barges. Assuming 15-barge tows, locks with and without tow haulage systems can process 8.7 and 6 tows per day, respectively.	Permanent tow haulage systems are currently in use during normal operations at Emsworth, Dashields and Montgomery L/D. Remains an option at 16 projects where 600' auxiliary lock is one-half the size of the main chamber.
Helper boats	When double lockages are required: 1) the last towboat to arrive at a congested project in the direction opposite of ongoing lockage operations disconnects from its barges, moves to the lock, and helps the tow locking through by extracting unpowered cuts of barges from the lock chamber. 2) It will then move the barges to a refleeting site away from the project so that tow reassembly does not interfere with lockage operations. 3) Help is provided to each tow until all barges have moved through the lock. Most Ohio River projects allow two cuts. Exceptions are the three uppermost projects, which allow up to five cuts per tow.	Typically reduces time a tow occupies a lock by as much 25 minutes. Time saved at the smaller Montgomery Lock is approximately 50 minutes.	Employed during lock closures at all projects with auxiliary chambers smaller than the main chamber.
SOURCE: USACE – Pittsburgh District 2003, Frechione & Walker 2003.			

Successful demand management measures encourage shippers to internalize congestion and environmental costs and focus on the efficient movement of goods, not just vessels, to reduce delays. The Transportation Research Board's Committee for the Study

of Freight Capacity for the Next Century (TRB 2002) has identified traffic demand management as a means of forestalling expensive capital investments in all modes of freight transportation. On waterways, traffic demand management measures are designed to reduce or redirect tow arrivals away from times when a lock is in heavy use. The goal of traffic demand management during lock closures is the complete avoidance by recreational watercraft of locks experiencing closures and a dramatic slowing in commercial tows arriving at the project. Although most measures are proposed to expedite river traffic during significant delays, some measures may be implemented on a full-time basis to reduce shipping costs or eliminate delays during normal use (Frechione & Walker 2003). Examples of such measures include shippers' self-imposed scheduling and increasing backhauls. The Ohio mainstem currently has the lowest empty barge return rates in the inland waterway. Between 22 to 28% of all barges return empty to their point of origin in contrast to up to 90% of upbound barges on the Mississippi returning empty (Dager, personal communication).

Table 10-7 compares and contrasts the two most frequently mentioned demand management measures.

TABLE10-7
Potential Traffic Demand Management Measures

Measure	How Measure Works	Effectiveness	Current Usage
Congestion fees	Charges tows a fee for processing through congested locks. Fees are aimed at reducing tow arrivals at congested locks to some "optimum" number that would maximize system benefits given lock closure inefficiencies.	Magnitude of delays is related to number of tows continuing to be processed through locks despite fees. Where congestion is directly related to structural condition problems, congestion fees have not performed well.	Implementation of such fees is considered in all Corps inland navigation studies, although pricing policies are not currently within the Corps' purview. Congestion fees will be evaluated in development of the System Investment Plan (SIP) for ORMSS.
Lockage appointment system	Requires shippers to have an appointment "slot" to lock through a project on a specific date at a specific time. With demand for slots likely exceeding lock capacity during closures, slots would be awarded to carrier via lottery or sale.	Use of this option to alleviate costly delays during closures has not been evaluated at Corps projects on the Ohio mainstem. Where congestion is directly related to structural condition problems, this option, like congestion fees, fails to address the major cause of periodic and costly closures. Among concerns related to	Not currently in use in the Ohio River system. A survey conducted by the Corps in 2001 revealed industry opinion that scheduling lockages would not be effective in dealing with delays, primarily because of difficulty in predicting tow arrival times at locks, given varying weather conditions and other factors. Also cited of concern was

Measure	How Measure Works	Effectiveness	Current Usage
		this option are when to require appointments, how to award slots, length of slots, and how to manage purchase/exchange of slots.	unfairness of locking tows except in the order that they arrive. Industry spokesmen favored helper boats as a more effective alternative.
SOURCE: Frechione & Walker 2003, (USACE - Pittsburgh District, 2000).			

Other measures that have been proposed include:

1) Use of vessel tracking systems to allow operational centers to locate and track all equipment moving on the river, enhancing identification of congestion areas and homeland security. Many large tows already are equipped with geopositioning systems (GPS) such that shippers can monitor their vessels and customers can locate their cargo.
2) A controlled schedule of shipments similar to that used on the Panama Canal, requiring passage through locks by appointment for the entire trip, not simply for a single lockage at a congested project. This concept has met with industry opposition due to unpredictability related to weather, potential crew inexperience, and other factors, and
3) Use of auxiliary locks to reduce normal delays. This is not time-effective even with normal delays, because it would take one-third more time to process a two-cut operation through an auxiliary lock than to process a one-cut operation through the main lock. Economically, it is not considered feasible because it would require installation and operation of a tow haulage system at an annual estimated cost of nearly three-quarters of a million dollars (USACE – Pittsburgh District 2003).

As **Table 10-7** indicates, the Corps' most recent analysis of traffic demand management measures (Frechione & Walker 2003), concluded that such measures do not perform well relative to structural solutions (e.g., lock extensions) when addressing episodic delays related to structural condition problems at specific projects. Frechione & Walker's report further states:

> Diminishing lock reliability due to unplanned failures of major lock components and more frequent maintenance and repair of heavily used, aging, structures will lead to degraded system performance at many locks, i.e., more tows sitting in queues incurring lengthy delays, a growing hesitancy on the part of shippers to use the waterway for bulk shipments, and increased reliance on overland modes that leads to greater exposure of the general public to highway congestion, the risk of accidents, and air pollutants. In this instance, structural alternatives more directly address the underlying problems of degraded lock conditions and their associated delays. Delays and the associated accumulation of delay costs that occur during normal operations of the locks are sizable. It is here that the more aggressive, price-related demand management measures may be most appropriate and, therefore, worthy of consideration.

Further, Frechione & Walker suggest that the Corps' Waterway Analysis Model (WAM), which is a lock simulation model, and the Ohio River Navigation Investment Model (ORNIM) can be combined to estimate potential benefits of scheduling under ideal conditions. Ideally, tows are spaced such that no delays occur because of simultaneous arrival of tows at a lock. If the combined models indicate that traffic scheduling under ideal conditions could realize significant benefits, additional work would be needed, including modification of WAM and ORNIM, to reflect varying levels of chaos in lock operations and tow movements.

Calculation of optimal congestion fees is challenging because such fees should incorporate the variables of time, lock, and commodity. Initial work has been completed to modify ORNIM within these constraints. ORNIM will examine a range of possible congestion fees, converge on an optimal fee, and include the cost of implementing and running a fee program within the overall analysis (Frechione & Walker 2003).

Nonstructural technical measures that increase system capacity, as well as potential traffic demand management measures, have some common environmental benefits. For example, all of these measures are focused on decreasing queuing prior to lock passage, and on moving barge traffic through the locks in a shorter time period and with a minimum of barge "cut operations." The environmental benefits include improvements in local water quality in or near potential queuing areas, areas used to accomplish "cut operations," and areas where "tow reassembly" typically occur. Reductions in damage and disruptions to shallow mussel beds would also be anticipated in areas in or near potential areas for queuing, areas for "cut operations," and areas for "tow reassembly."

10.7.5 TRANSPORTATION EFFICIENCIES, COMMODITIES TRANSPORTED, AND TRAFFIC DEMAND FORECASTING

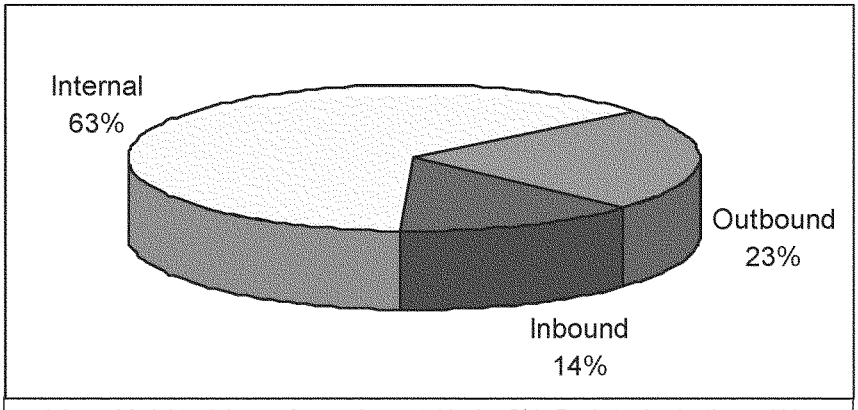
Inland waterways carry 11 percent of domestic intercity ton-miles nationwide, but account for only 1 percent of freight expenditures, making inland shipping the cheapest freight mode in terms of average transportation cost per ton-mile (Wilson 2001, cited in Transportation Research Board 2002). Barge transportation also is the most energy efficient mode for carrying large quantities of bulk commodities. A typical jumbo barge (195' x 35') can transport as much coal or grain as 15 rail cars for one-fourth the energy per ton-mile (USACE – Huntington District 2003). A typical Ohio River tow consisting of 15 barges and carrying a total of 22,500 tons is equivalent to 225 railcars or 870 semi-trucks.

As **Figure 10-3** indicates, 63 percent of traffic on the Ohio River system is internal (i.e., confined to the Ohio mainstem and navigable tributaries). In 2001, 87 % of traffic within the Ohio River system moved on the mainstem (see **Table 10-8**).

Growth on the Ohio mainstem has proceeded at a faster pace than the Ohio River system as a whole, reflecting the relatively recent navigation development of the mainstem, compared with some of the tributary streams like the Monongahela and Kanawha Rivers. Since 1990, growth on the Ohio mainstem has slowed somewhat from its rapid 1940-1990 pace, when it averaged 4.2 percent annually. The annual growth rate for the mainstem from 1990 to 2001 was 0.7 percent (USACE – Huntington District 2003). Since 1996, and through 2003, total mainstem traffic has stabilized around 240 million tons per year.

The average haul length on the Ohio River is about 400 miles, which is the lowest average haul length in the inland waterway system (Dager, personal communication). Haul length is directly related to the nature of commodities shipped, their origins, and destinations. Commodities transported on the Ohio River system are the products of coal mines, petroleum refiners, stone quarries, cement plants and farms, along with raw materials for construction companies, steel mills, electric utilities, paper plants, aluminum manufacturers, and chemical companies – the foundation of the region's economy. Commodity traffic flow at a given lock and dam is largely determined by its geographic location. The commodity mix consequently influences barge type and flow configuration (USACE 2000).

FIGURE 10-3
Ohio River System Traffic



Inbound freight originates from points outside the Ohio Basin to destinations within the Basin. Outbound is freight from within the Basin to points outside. Internal freight moves entirely from one port to another within the system.

SOURCE: SIP Economics Appendix, USACE – Huntington District (2003).

TABLE 10-8

Historic Ohio River System and Mainstem Ohio Traffic (million tons)

Year	Ohio River Mainstem	Ohio River System	Mainstem %
1940	29.5	51.2	58%
1950	48.6	66.1	74%
1960	79.5	105.3	75%
1970	129.6	163.9	79%
1980	174.9	200.5	87%
1990	225.7	257.8	88%
2000	236.3	271.7	87%
2001	242.5	279.9	87%
Avg. Annual:			
1940-01	**3.5%**	**2.8%**	
1990-01	**0.7%**	**0.8%**	

Source: Waterborne Commerce Statistics Center data cited in SIP Economics Appendix, USACE – Huntington District (2003)

Like the Ohio River system, Ohio River mainstem traffic is dominated by transport of coal. Since the 1970s, over 50 percent of the tonnage of commodities shipped on the Ohio River mainstem each year has been coal (**Table 10-9**). Coal transport historically has been more prevalent on the upper portion of the Ohio River than on the lower portion. The primary markets for coal shipments are domestic electric utility plants. Coal traffic also moves to coal blending facilities, industrial facilities, and coking facilities. These three coal destinations, however, collectively accounted for less than 20 percent of the total coal traffic in 2000 (USACE-Huntington District 2003). Although **Table 10-9** shows a 2.5 percent annual increase in coal traffic from 1965 through 2003, coal traffic declined (-0.9% annually) for the interval from 1993 through 2003 To some extent, changes in the coal export market account for this decline. The export market for Ohio River coal has been relatively flat in recent years due to increasing competition from other exporting countries and the movement of many importers away from coal for environmental reasons. Additional information on intermodal transport is included in the following section.

The dominance of electric utility coal transport on the Ohio River and attention focused on coal by the government and the public are reflected in the Corps' most recent traffic demand forecasts, which place special emphasis on utility coal and the sorbent materials (lime and limestone) used for coal desulfurization. While other commodities and barge-served markets face uncertainty, none equals the dominance of coal or level of uncertainty regarding future use. Deregulation is affecting the electric utility industry, but experts acknowledge that environmental regulations will be the dominant factor affecting future coal utilization and sourcing by the electric utility industry. In light of this, the Corps has developed five alternative traffic forecast scenarios presented in detail in (USACE-Huntington District 2003). These scenarios are being used in the economic analyses being conducted as part of the SIP.

TABLE 10-9
Historic Ohio River Mainstem Traffic by Commodity
(Million tons)

Year	Coal	Petrol	Aggs	Grain	Chem	Ores	Iron	Other	Total
1965	46.6	20.5	14.2	2.6	6.0	7.6	3.4	2.3	103.2
1970	59.0	25.3	17.2	3.6	10.6	3.9	4.4	5.5	129.5
1975	73.3	19.6	16.5	4.1	9.1	3.5	3.9	10.1	140.1
1980	86.1	18.3	21.2	6.7	11.5	3.2	4.1	9.6	160.7
1985	98.2	12.5	20.9	11.7	12.7	3.5	5.0	13.4	177.9
1990	135.1	14.4	30.4	13.2	9.3	5.5	6.5	11.2	225.6
1991	131.6	13.9	27.0	10.2	9.0	5.7	6.2	14.8	218.4
1992	134.7	13.3	28.1	11.3	9.6	5.5	5.8	18.1	226.4
1993	130.3	14.2	29.5	14.0	10.5	5.9	7.5	17.6	229.5
1994	134.8	14.2	32.2	12.0	10.2	6.8	9.6	17.0	236.8
1995	130.0	13.6	33.3	12.0	10.2	6.7	10.1	18.2	234.1
1996	134.8	13.2	37.3	10.7	9.4	7.5	9.7	15.1	237.7
1997	135.1	12.8	39.9	10.9	9.6	6.8	9.5	15.4	240.0
1998	132.7	20.2	42.9	13.9	9.8	5.9	10.2	6.3	241.9
1999	124.8	20.6	43.2	15.2	10.0	6.6	12.1	8.4	240.9
2000	118.9	20.2	40.9	15.6	10.2	6.9	14.3	9.5	236.5
2001	128.0	20.3	40.8	18.0	9.7	6.8	10.9	7.9	242.4
2002	131.0	19.7	39.1	16.9	9.7	6.4	12.4	7.6	242.8
2003	118.5	16.3	41.7	13.8	10.3	7.4	13.9	6.8	228.8
Avg. Ann. Growth Rate									
(1965 - 2003)	**2.5%**	**-0.6%**	**2.9%**	**4.5%**	**1.4%**	**-0.1%**	**3.8%**	**2.9%**	**2.1%**
(1993 - 2003)	**-0.9%**	**1.4%**	**3.5%**	**-0.1%**	**-0.2%**	**2.3%**	**6.4%**	**-9.1%**	**0.0%**

Source: Waterborne Commerce Statistics Center data cited in SIP Section 4

Recent trends in the other important commodities reflect growth rates exceeding 4.0 percent annually in aggregates, grain, and iron. Aggregates consist primarily of crushed limestone, sand and gravel, and building stone and accounted for just under 17 percent of traffic at all mainstem locks in 2003. These construction materials typically are extracted as close as possible to their market areas; therefore, aggregate traffic on the Ohio River is frequently short-haul and may be entirely within one pool. These intra pool movements are included in the ORNIM shipment list and reported as part of system statistics; however, they do not contribute to lock delays.

Grain traffic, consisting primarily of corn, wheat, and soybeans, composed 7.4 percent of Ohio mainstem traffic in 2001. The three Ohio River basin states of Ohio, Indiana, and Illinois produce about one-quarter of the nation's corn and soybeans. In 2000, approximately 71 percent of the grain traffic on the Ohio River system was outbound, primarily for export markets; 20 percent was inbound, primarily for grain processors on the Tennessee River, and about 9 percent was destined for internal processors along the Ohio mainstem.

Transport of iron on the system has changed with the massive changes undergone by the iron and steel industry in recent decades. Within the Ohio River system, only four integrated steel mills remain in operation, out of about a dozen that were operating as recently as 1980. Scrap iron is important to mini mills, integrated mills are a critical source of scrap iron, and this has contributed somewhat to the present distribution of mini mills within the Ohio River system. Mini mill location is also influenced by electricity cost, scrap availability, transportation, and access to final customer.

The availability and quality of scrap potentially limits the quantity and, more importantly, quality of steel a mini mill can produce. Mini mills with processes capable of using Direct Reduced Iron (DRI) have the ability to produce the high quality steel required by appliance and auto manufacturers by adding high quality DRI to scrap. Hot Briquetted Iron (HBI) is a type of DRI produced from high quality iron ore. HBI used in Ohio River Basin mini mills originates in South America and some of it moves on barges from New Orleans up the Ohio. In addition, integrated steel mills have recently begun moving South American iron ore to New Orleans and then barging the ore to plants in the Ohio Valley.

Detailed traffic demand forecasts for each of the commodities discussed in these paragraphs are included in Attachment 3 to the ORMSS SIP/PEIS Economics Appendix (USACE-Huntington District 2003).

The Corps has developed detailed lock-level traffic demand forecasts (included in Table 11 of Attachment 3 of the SIP?PEIS Economics Appendix). These forecasts reflect the effects of coal source switching by electric utilities to comply with existing or proposed environmental regulations. The most recent forecast growth rates are highest for some upper Ohio projects (e.g., Willow Island and Belleville L/Ds) and for projects on the lower river. These rates reflect anticipated increases in use of Northern Appalachian coal and Illinois Basin coal by electric utilities, as well as increases of western coals coming into the Ohio River system. The lower costs of Northern Appalachian and Illinois Basin coals coupled with improving scrubber technology to desulfurize coal make use of these coal sources more attractive to utilities than in the past. Conversely, reduced availability and increased production costs of Central Appalachian coal are anticipated to be reflected in lower traffic growth rates at locks in the middle river. Projected lower growth rates at the uppermost Ohio River locks suggest increased usage of local coal on the Monongahela and upper Ohio.

10.8 Ohio River Mainstem Traffic and Intermodal Connections

State profiles from the U.S. Department of Transportation's Freight Analysis Framework (FAF) were reviewed to obtain a comprehensive perspective on current and future freight movement in the six states bordering the Ohio River. Benchmark dates used in the framework were 1998, 2010, and 2020. **Figure 10-5** shows that the proportions of truck, rail, and water transportation are expected to remain relatively consistent in each state from 1998 through 2020, although tonnages by mode are expected to increase.

In all states except West Virginia, highway transportation (i.e., by truck) is by far the leading freight mode, comprising as much as 72% of the freight traffic in Indiana in 1998. Truck transportation is expected to gradually increase in tonnage and percent of total freight in all states throughout the forecast period. The maximum prediction is for 2020 in Ohio, where trucks are predicted to transport 76% of the total freight. Value of goods is an important variable in truck transportation. In general, higher value commodities are trucked longer distances than lower value commodities.

Only in West Virginia was rail the dominant mode, carrying about 51% of freight in 1998. Rail is expected to be the dominant freight mode in West Virginia through 2020. **Figure 10-4** shows rail carrying 45% of the West Virginia tonnage in 2020 as compared to

37% by truck. However, the overall tonnage of commodities transported by rail is expected to remain flat or slightly decline in all six Ohio River states. Similarly, water transportation is expected to remain flat or slightly decline in all states except Illinois, which will experience a slight increase in water transportation. The freight analyses are statewide and do not specifically break out the proportion of water traffic on the Ohio mainstem from tributaries, Great Lakes traffic, or Upper Mississippi-Illinois Waterway traffic.

The FAF also looks at the principal commodities by weight. In 1998, coal and nonmetallic minerals ranked as the top two commodities in all states except Illinois. Coal and nonmetallic minerals were first and second, respectively, in commodity flows from West Virginia and Kentucky, while the opposite order occurred in commodity flows from Pennsylvania, Ohio, and Indiana. Coal and nonmetallic minerals will continue to be important throughout the forecast period. During 1998, farm products were the top commodities from Illinois, closely followed by nonmetallic minerals and coal.

The Transportation Rate Study (TRS) (2001) performed by the Tennessee Valley Authority for the Corps' Navigation Center in Huntington, WV, provides more specific information on the Ohio River system than the more generalized commodity movement picture provided by the FAF. The TRS reviewed approximately 1,600 commodity movements, which included 83% of tonnage on the Ohio River system during the study period. The TRS revealed that intermodal connections with Ohio River system traffic vary not only by commodity but also by a commodity's origin. The dominant commodity, coal, illustrates this point.

Coal, mined in the upper Ohio Valley, historically has been moved a relatively short distance (<100 miles) to barge loading facilities. Currently, overland coal transportation in the upper Ohio is about 40% by truck, about 10% by rail, and the remaining 50% by conveyor belt (up to 10 miles long) or direct loading at a mine mouth. Since 1992, lower sulfur Western coal, primarily from Wyoming, has been transported 1,500 to 1,800 miles by rail to lower Ohio River transfer facilities, such as the Cook Coal Terminal at RM 947.5 at Metropolis, IL, that is owned by American Electric Power. After loading on the lower river, Western coal travels 200 to 800 miles upriver to coal blending facilities and power plants. A secondary effect of the influx of Western coal on the system has been a reduction in the amount of sand and gravel backhauled, because barge operators receive a higher price for hauling coal than for hauling sand and gravel. As scrubbers and other clean air technologies are introduced at electric generating plants, however, the demand for Western coal is expected to decrease and the present trend may be reversed. This reversal, in turn, may benefit the sand and gravel industry.

Grain transportation also is related to point of origin. Most grain barges are downbound on the river for export. The TRS showed that currently about 95% of grain arrives at river terminals by truck while only about 5% arrives by rail. The primary rail connections are at Evansville and Mt. Vernon, IN, and Mound City, IL. Grain arrives at river terminals in the larger cities of Cincinnati and Louisville exclusively by truck. The TRS found that about 50% of river terminals have rail access, but only 5 to 10% use it, primarily because connections are with the wrong rail companies. For example, the Norfolk Southern and CSX railroads have numerous connections at barge terminals, but these railroads are not key players in grain transport. Also, in some cases, railroads at

barge terminals lack the necessary connections with other lines for cost effective transport of goods.

The transport of steel and related materials on the Ohio River system also has been affected by different points of origin and material inputs dating from more than 20 years ago, when larger integrated steel mills dominated. Today's steel minimills depend in part on iron intermediates from Brazil and Venezuela that travel upriver from New Orleans, effectively reversing traffic patterns that prevailed earlier. This upbound trend is expected to continue into the foreseeable future. In addition to affecting Ohio River traffic, the minimill trend has reduced iron ore traffic on the Great Lakes (Dager, personal communication).

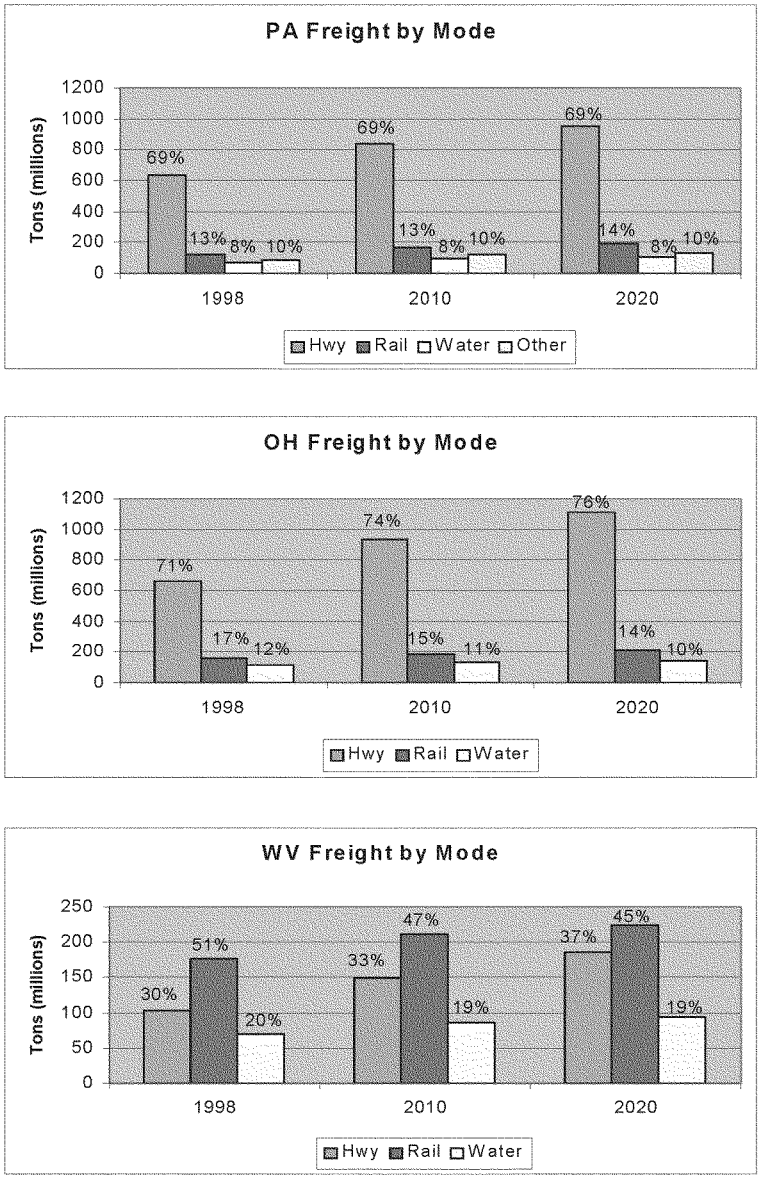
Future transportation demands relative to Ohio River system capacity by mode are more difficult to assess. The TRS did not review traffic movements with regard to capacity, but assumed that system capacity would be built as needed. The Transportation Research Board's (TRB) special report on Freight Capacity for the 21st Century (2002) was reviewed to gain an understanding of capacity problems the freight industry is experiencing today nationwide. The TRB's report, however, does not forecast future capacity or traffic volumes, presumably because numerous factors can complicate such predictions and compromise their reliability. For water transportation, the report noted that capacity constraints on the inland waterway include aging infrastructure and peak-period congestion at certain locks. Rail capacity constraints are also localized in time and space, but most trends are consistent with tightening capacity, including long-term contraction of the rail network. In general, the report concluded that if the nation's addition of

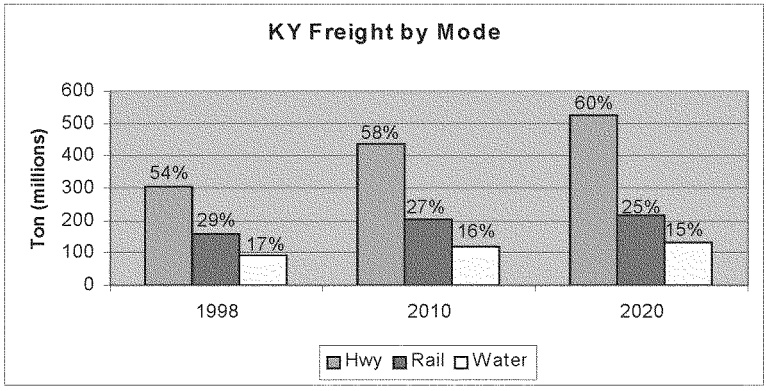
transportation capacity does lag traffic growth and congestion worsens, as seems likely, long-run consequences will not be a "massive breakdown."

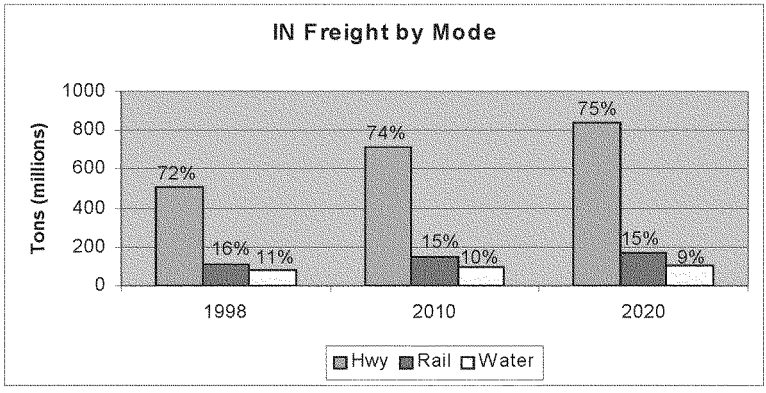
Several factors the TRB identified as affecting transportation efficiencies and capacity include:

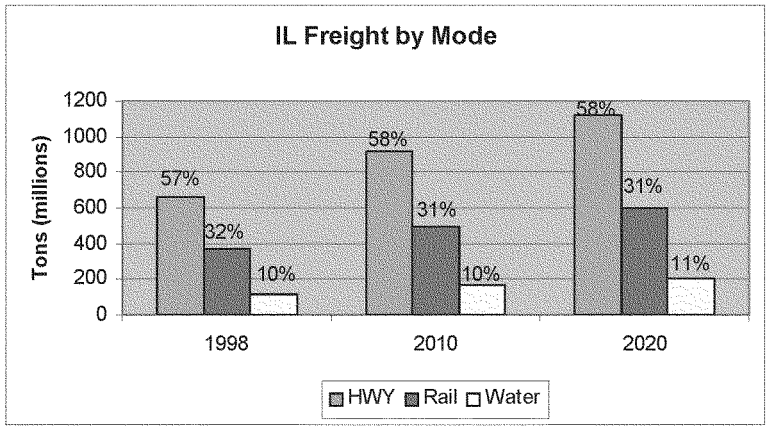
1) continued changes in character of freight demand (e.g., the changing Ohio River coal scenario)
2) potential changes in government regulations of vehicles (e.g., truck size and weight regulations that affect highway capacity)
3) international trade policies
4) improvements in infrastructure that can facilitate traffic movement
5) management, operational, and financial changes that can markedly improve efficiency (e.g., information technology that improves coordination and scheduling of water or overland shipments)
6) changing population densities and demographics (e.g., shifts in percentage of working age populations)
7) overall urbanization and competing land uses and
8) air and water pollution control requirements.

FIGURE 10-5
Comparison of Total Annual Freight by State and Mode









Source: U.S. Department of Transportation's Freight Analysis Framework

10.9 INTERACTIONS WITH OTHER VECS

The four-fold increase in shipping traffic demands on the Ohio River since 1950 has been accompanied by increasing interactions with several other Valued Environmental Components (VECs). Land use and socioeconomics along the Ohio River are closely linked with river transportation and traffic, as well as with surface and air transportation. The growth of recreation on the river, in turn, is related to land use and socioeconomic factors.

Concerning mussels and fish, operation and maintenance of the navigation system have resulted in habitat changes that have shifted the fauna away from riverine species to those more suited to lake-like conditions. The chapters on mussels and fish provide additional details on ways the navigation system and traffic movement influence distribution and reproductive success of species in these groups. Good water quality, essential for healthy aquatic life, is influenced by potential spills and handling of commodities transported and transferred on or near the river.

River traffic does not interact highly with cultural resources, but the infrastructure that supports traffic, including terminals, has affected cultural resources through burial and loss as terminals and related infrastructure are developed. Pool maintenance, which enables navigation, continues to inundate some cultural resources in the floodplain. The reduction in natural fluctuations of water levels due to pool maintenance also has caused changes in riparian resources and floodplain hydrology.

Traffic and transportation are linked directly to air quality, although emissions from tows represent less than 3 percent of mobile source emissions along the Ohio River corridor (see Chapter 7, Air Quality). Aesthetics also are affected by traffic, although such impacts are difficult to measure because of their subjective nature.

10.10 RELEVANT ACTIONS AFFECTING TRANSPORTATION AND TRAFFIC

In considering the relevant actions discussed in this section, it is important to reiterate that "transportation and traffic," as defined for ORMSS, concern the conveyance of goods and people along the Ohio River mainstem and related traffic activities and efficiencies. Consequently, transportation and traffic focus primarily on human activities and communities within the CEA planning context. In this regard, beneficial effects are considered as those that will improve the conveyance of goods and people along the Ohio River mainstem. Detrimental effects are considered as those that reduce the efficiency of conveyance of goods and people. The numerous interactions that occur among transportation and traffic and environmental resources and ecosystems are explored in more detail elsewhere in this document, especially in the chapters on water quality, mussels, fish, and riparian resources.

The RFFA matrix for Transportation and Traffic (**Table 10-10**) shows that 45 of the RFFAs listed were not ranked either because they are not applicable or links to

Transportation and Traffic are weak. Many RFFAs were ranked low because individually they have little influence on transportation or traffic.

The 21 RFFAs ranked high (H) or medium (M) in importance are discussed below in the context of:

- Actions directly affecting traffic
- Actions related to commerce on the river and
- Actions conflicting with barge traffic.

TABLE 10-10
RFFA Cumulative Effects Matrix for Transportation and Traffic

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Transportation	Importance[5]
Navigation Investment Actions					
Lock Extensions/New Locks/Replacement or Rehabilitation	A	H	SL	(+)	H
L&D operation and maintenance	A	H	SL	(+)	M
Non-structural navigation improvements	A	H	SL	(+)	M
Dam replacement and rehabilitation	A	H	SL	(+)	H/M
Other Corps Actions					
Flood damage reduction projects					
dry dams, other projects off mainstem	A	L	SL	(+)	M
Recreation facilities - Construction and O&M	A	H	SL	(-)	M
Port development (Sec. 107) and maintenance dredging	A	H	SL	(+)	M
"But for" Actions					
Commercial Navigation					
barge queuing	A	H	SL	(-)	M
terminals	A	H	SL	(+)	M
multi-modal sites	A	H	SL	(+)	M
increased traffic	A	H	E	(+)	M
Coal utilities	A	H	SL	(+)	H
Other coal industries	A	M/L?	SL	(+)	M
Industrial users, excluding coal-related	A	H	SL	(+)	H
Recreation facilities - Construction and O&M	A	H	SL	(-)	M
Actions by Others					
Marina development & operation	A	H	SL	(-)	M
Water -based recreation					
boating	A	H	E	(-)	M
fishing	A	H	E	(-)	M
PWCs	A	H	E	(-)	M
Natural Climatic Events					
floods	A	H	E	(-)	L/M
droughts	A	H	E	(-)	L/M

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Transportation	Importance[5]
Regulatory Environment					
COE permitting programs	A	H	E	(-)	M
ORSANCO monitoring program	A	H	E	(+)	M
[1] Reasonably Foreseeable Future Actions					
[2] Time period in which the RFFA may occur:					
1 = within 10 years, 2 = in 10 - 25 years, 3 = in 25 - 60 years, A = applicable for all time periods					
[3] Occurrence probability or likelihood RFFA will happen					
H = high, M = medium, L = low					
[4] Location or setting on river where RFFA is expected to occur:					
U = upper (Pittsburgh - Huntington), M = middle (below Huntington - Louisville), L = lower ((below Lousiville - mouth), E = along entire length of river, SL = specific location, e.g., locks and dams, U = urban setting, R = rural setting					
[5] Importance of RFFA: H = high, M = medium, L = low					

10.10.1 Actions Directly Affecting Traffic

This category includes actions that facilitate or impede traffic flow on the river; it is primarily related to locks and dams and to other projects or facilities that support commercial navigation.

The RFFA listed as lock extensions/replacements (H) involves expanding lock chambers from 600' to 1200' at up to seven navigation projects between R.C. Byrd and Smithland L/D. Replacements involve replacing small 360' auxiliary lock chambers at Emsworth, Dashields, and Montgomery L/D in the upper river, with 600' or 1200' main chambers. This action is considered beneficial because it would reduce traffic delays and provide more capacity. Lock maintenance, repair, and rehabilitation (M), if proactive, would be beneficial by keeping the navigation system efficient, but would not be expected to increase system capacity. In general, additional capacity is not needed if locks are reliable and efficient. Negative impacts on transportation and traffic as these activities are implemented are temporary. Nonstructural navigation measures (M), by definition, do not involve construction or temporary closures, but facilitate traffic movements in congested areas through several means. In contrast, barge queuing (M), associated with all three previously mentioned RFFAs, has a negative effect on the navigation system because it impedes traffic flow and occurs frequently.

Dry dams and other projects off the Ohio mainstem (M) do not affect overall system traffic capacity, but are considered important and beneficial because they aid in decreasing or supplementing flows during floods or droughts. Although floods and droughts (both ranked M/L) are not frequent occurrences, the problems they cause can have major, short-term adverse effects on navigation.

In general, the development of terminals (M) and multimodal sites (M) would facilitate movement of commodities in the navigation system and enhance links with other modes of transportation. The benefits of developing an individual facility and negative

aspects of construction, however, are to some extent dependent on a facility's location along the river and the type of commodity handled. These projects and other activities subject to Corps permitting programs (M) which may involve dredging, discharges and conversion of wetlands during development can cause conflicts and disruptions in relation to navigation traffic and are considered negative in the short term.

10.10.2 Activities Related to Commerce on the River

Both coal utilities and industrial users (other than coal) are RFFAs ranked as having high (H), positive importance to the Transportation and Traffic VEC because they represent a high proportion of commerce on the Ohio mainstem. Previous sections of this chapter have emphasized the commercial importance of these activities by tonnage, as well as the profound effects changing needs of industry can have on transportation demand. Also grouped in this category and ranked beneficial is the RFFA called increased traffic (M), which refers to additional barge traffic on the Ohio mainstem with or without future improvements to the lock and dam system.

10.10.3 Actions that Conflict with Barge Traffic

This category includes several RFFAs, all ranked medium (M), that either directly conflict with barge traffic or that support recreational activities that conflict with barge traffic. Boating, fishing and the relatively recent use of personal water craft (PWC) have the potential to conflict with barge traffic and raise safety concerns, including noise in some cases. Marina development and operation and construction and operation of river-related recreation facilities both by the Corps and other entities ensure the continuance and growth of recreation activities that promote conflicting river uses.

10.11 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

One of the seven environmental operating principles of the Corps is to strive to achieve environmental sustainability (ES). ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation, and maintenance to improve the quality of life for present and future generations. Accordingly, ES represents an "ultimate test" whereby the significance of CEs can be evaluated. This test is applicable for programmatic impact studies wherein a broad, "high altitude" perspective is utilized. An AES has been and is being used in several other programmatic studies by the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps: (1) delineation of "common effects" on 9 identified metrics from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix; (2) selection of indicators for ES for transportation and traffic, and their grouping, as appropriate; and (3) consideration of the "connections" between the common effects and the indicator groups. Output of AES consists of a qualitative (descriptive) discussion of the "connections," with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions -- what is the current ES for

transportation and traffic, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable -- composite conditions and selected contributing indicators of ES for transportation and traffic do not reflect conditions that would facilitate meeting societal needs over time by an appropriate blending of economic and environmental concerns; these conditions periodically occur at a large number of the locks along the river.

- Marginally sustainable -- composite conditions and selected contributing indicators of ES for transportation and traffic are problematic at several locations along the Ohio River; these problematic conditions are somewhat tenuous both in location and likelihood of occurrences, thus periodic short-term declines in the cost-effectiveness and efficiency of the movement of goods, and associated increases in externalities, would be expected to occur.

- Sustainable -- composite conditions and selected contributing indicators of ES for transportation and traffic are such that sustained conditions of cost-effectiveness and efficiency, along with the minimization of externalities, are achieved along the majority of the river.

ES of the waterway transportation system on the Ohio River mainstem includes three features:

(1) It is "cost-effective and efficient" in that it is affordable, operates efficiently, connects with other transportation modes, and supports a vibrant economy.

(2) It "minimizes externalities" in that it limits emissions and waste within the environment's capacity to handle them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes use of land and production of noise.

(3) It "meets societal needs over time by an appropriate blending of economic and environmental concerns;" this can occur as a result of allowing the basic needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations.

Accordingly, these three features (or indicators of ES) can be considered in the following manner -- number (3) reflects the "composite indicator" of ES for transportation and traffic, while numbers (1) and (2) represent contributing indicators to (3).

Nine environmental indicators were identified earlier, and relevant data and information on them have been presented in the sections entitled "Past to Current Baseline Conditions," and "Ohio River Mainstem Traffic and Intermodal Connections." The environmental indicators can be considered as metrics that are related to either the "cost-effective and efficient" ES feature, or the "minimize externalities" ES feature as follows:

- Cost-effective and efficient

  -- Barge tonnage passing through each lock over time
  -- Annual barge tonnage with origin and destination within the Ohio River navigation system
  -- Annual barge tonnage with origin in the system but moved out of the system
  -- Annual barge tonnage with origin outside the system but moved into the system
  -- Percentages of different commodities transported along the river over time and
  -- Numbers of terminals and intermodal transfer facilities over time

- Minimize externalities (note that the following three metrics could also be listed for "cost-effective and efficient")

  -- Average queuing times for barge traffic at locks over time
  -- Capacity and condition of rail and highway links in the study area and
  -- Amount and types of fuel used by tows over time (will be less than fuel usage per ton-mile by trains and trucks)

As noted above, the 21 RFFAs ranked as high (H) or medium (M) can be grouped into actions directly affecting barge traffic (either by enhancing or potentially decreasing traffic movement), actions that increase commerce, and actions that conflict with barge traffic. These four groups of actions, along with nine environmental indicators and three features related to ES for transportation and traffic, are displayed in **Tables 10-11 through 10-14**. **Table 10-11** includes nine RFFAs that are anticipated to enhance barge traffic on the Ohio River mainstem. The connections between the RFFAs and the six measures related to cost-effectiveness and efficiency, and the three measures related to minimizing externalities are summarized in the table. Finally, the right-most column summarizes resulting effects on the three composite indicators of transportation and traffic sustainability. In general, it can be seen that these actions would move the waterway navigation system toward a more sustainable condition.

Table 10-12 relates to the two RFFAs that are anticipated to decrease navigation traffic movement. The structure of **Table 10-12** is similar to that for **Table 10-11**. In general, it can be seen that the two RFFAs in **Table 10-12** are anticipated to cause periodic and temporary movement of the waterway navigation system away from a sustainable condition.

Table 10-13 addresses four RFFAs that are expected to increase commerce along the Ohio River mainstem. The structure of this table is similar to **Tables 10-11 and 10-12**. The underlying assumption for **Table 10-13** is that the "commercial" increases would occur without navigation investment actions. If so, these RFFAs would move the waterway navigation system away from a more sustainable condition.

Finally, **Table 10-14** highlights the CEs of six RFFAs that are anticipated to cause conflicts with barge traffic movement. Again, the structure of **Table 10-14** is similar to that for **Tables 10-11 through 10-13**. As shown in **Table 10-14**, the six RFFAs would move the waterway navigation system away from a sustainable condition.

To summarize the relationships between the CEs of the 21 high and medium importance RFFAs and transportation and traffic sustainability, the following key points are noted:

- Groups of actions that are anticipated to improve the ES of transportation and traffic include those that enhance navigation traffic movement, and those that increase commerce (if it is assumed that navigation investment actions occur).

- Groups of actions that are anticipated to move the waterway navigation system away from a more sustainable condition include those that decrease traffic movement, those that increase commerce (if it is assumed that navigation investment actions will not occur), and those that cause conflicts with traffic movement (these are primarily water-based recreational RFFAs)

TABLE 10-11
AES Tiers for Actions That Enhance Navigation Traffic Movement

RFFAs That Enhance Navigation Traffic Movement	Measures (Metrics) Related to Cost-Effectiveness and Efficiency (See Notes)	Measures (Metrics) Related to Minimizing Externalities (See Notes)	Composite Indicators of transportation and Traffic Sustainability
• Lock extensions, new locks, replacement or rehabilitation (H) • L & D operation and maintenance (M) • Non-structural navigation improvements (M) • Dam replacement and rehabilitation (H/M) • Dry dams (M) • Port development and maintenance dredging (M) • Terminals (M) • Multi-modal sites (M) • ORSANCO monitoring program (M)	Increases are expected for (1), (2), (3), (4), (5), and (6) over time; such increases should lead to increased cost effectiveness and efficiency for the movement of goods.	Decreases are expected for (7). For (8), it may be necessary to repair and improve existing rail and highway links in the study area in order to meet multi-modal demands. For (9), increases in the total externalities are expected; however, they would be less than condition if all goods moved via rail or highway links.	• Cost-effectiveness and efficiency -- increases are expected • Minimizes externalities -- decreases in emissions are expected, relative to rail and highway modes for the sole movement of goods • Meets societal needs over time by an appropriate blending of economic and environmental concerns -- would move the waterway navigation system towards a more sustainable condition.

Notes: The measures (metrics) in numbered order are as follows:

(1) Barge tonnage passing through each lock over time
(2) Annual barge tonnage with origin and destination within the Ohio River navigation system
(3) Annual barge tonnage with origin in the system but moved out of the system
(4) Annual barge tonnage with origin outside the system but moved into the system
(5) Percentages of different commodities transported along the river over time
(6) Numbers of terminals and intermodal transfer facilities over time
(7) Average queuing times for barge traffic at locks over time
(8) Capacity and condition of rail and highway links in the study area and
(9) Amount and types of fuel used by tows over time.

TABLE 10-12
AES Tiers for Actions That Decrease Navigation Traffic Movement

RFFAs That Decrease Navigation Traffic Movement	Measures (Metrics) Related to Cost-Effectiveness and Efficiency (See Notes)	Measures (Metrics) Related to Minimizing Externalities (See Notes)	Composite Indicators of Transportation and Traffic Sustainability
• Barge queuing (M) • COE permitting programs (M)	Barge queuing at specific locks, along with water-side construction and operational activities associated with permitting, would be expected to cause decreases for (1), (2), (3), (4), (5), and (6) over time; such decreases should lead to decreased cost effectiveness and efficiency for the movement of goods.	Barge queuing at specific locks, along with water-side construction and operational activities associated with permitting, would be expected to increase (7) and lead to increased air pollution and water quality disturbances. Increased requirements would occur relative to increasing the capacity of rail and highway links.	• Cost-effectiveness and efficiency -- periodic and temporary decreases are expected • Minimizes externalities -- periodic and temporary increases in emissions are expected, and greater usage of rail and highway modes for the sole movement of goods are expected • Meets societal needs over time by an appropriate blending of economic and environmental concerns -- would cause periodic and temporary movement of the waterway navigation system away from a more sustainable condition.

Notes: The measures (metrics) in numbered order are as follows:

(1) Barge tonnage passing through each lock over time
(2) Annual barge tonnage with origin and destination within the Ohio River navigation system
(3) Annual barge tonnage with origin in the system but moved out of the system
(4) Annual barge tonnage with origin outside the system but moved into the system
(5) Percentages of different commodities transported along the river over time
(6) Numbers of terminals and intermodal transfer facilities over time
(7) Average queuing times for barge traffic at locks over time
(8) Capacity and condition of rail and highway links in the study area and
(9) Amount and types of fuel used by tows over time.

TABLE 10-13
AES Tiers for Actions That Increase Commerce

RFFAs That Increase Commerce	Measures (Metrics) Related to Cost-Effectiveness and Efficiency (See Notes)	Measures (Metrics) Related to Minimizing Externalities (See Notes)	Composite Indicators of Transportation and Traffic Sustainability
• Increased navigation traffic (M) • Coal utilities (H) • Other coal industries (M) • Industrial users, excluding coal-related (H)	Increases in "commercial" actions, without the associated navigation investment actions, would be expected to cause increased system demands; however the result would be expected decreases for (1), (2), (3), (4), (5), and (6) over time; such decreases should lead to decreased cost effectiveness and efficiency for the movement of goods. If such increases in commercial actions occur in conjunction with navigation investment actions, there would be expected increases in the cost-effectiveness and efficiency for the movement of goods.	Increased system demands, without the associated navigation investment actions, would be expected to increase externalities such as fuel usage (9), and water quality disruptions from barge queuing (7). Greater demands would also be placed on the capacity of existing rail and highway links (8). If such increases in commercial actions occur in conjunction with navigation investment actions, there would be expected increases in the composite indicators of transportation and traffic sustainability.	• Cost-effectiveness and efficiency -- decreases are expected without navigation investment actions. • Minimizes externalities -- increases in emissions are expected, relative to rail and highway modes for the sole movement of goods • Meets societal needs over time by an appropriate blending of economic and environmental concerns -- would move the waterway navigation system away from a more sustainable condition.

Notes: The measures (metrics) in numbered order are as follows:

(1) Barge tonnage passing through each lock over time
(2) Annual barge tonnage with origin and destination within the Ohio River navigation system
(3) Annual barge tonnage with origin in the system but moved out of the system
(4) Annual barge tonnage with origin outside the system but moved into the system
(5) Percentages of different commodities transported along the river over time
(6) Numbers of terminals and intermodal transfer facilities over time
(7) Average queuing times for barge traffic at locks over time
(8) Capacity and condition of rail and highway links in the study area and
(9) Amount and types of fuel used by tows over time.

TABLE 10-14
AES Tiers for Actions That Causes Conflicts With Barge Traffic Movement

RFFAs That Cause Conflicts With Barge Traffic Movement	Measures (Metrics) Related to Cost-Effectiveness and Efficiency (See Notes)	Measures (Metrics) Related to Minimizing Externalities (See Notes)	Composite Indicators of Transportation and Traffic Sustainability
• Recreation facilities - construction and O & M (Corps) (M) • Recreation facilities - construction and O & M ("but for" actions by others) (M) • Marina development and operation (M) • Water-based recreation-boating (M) • Water-based recreation -fishing (M) • Water-based recreation-PWCs (M)	Increased water-based recreational usage, if at a sufficient level, would be expected to cause decreases in (1), (2), (3), (4), (5), and (6) over time; such decreases should lead to decreased cost effectiveness and efficiency for the movement of goods.	Increases are expected in average queuing time (7) and fuel usage by tows (9); further, greater demands will be placed on moving goods via rail and highway links (8), thus increasing the externalities.	• Cost-effectiveness and efficiency -- decreases are expected • Minimizes externalities -- increases in emissions are expected, particularly due to greater dependency on rail and highway modes for the sole movement of goods • Meets societal needs over time by an appropriate blending of economic and environmental concerns -- would move the waterway navigation system away from a more sustainable condition.

Notes: The measures (metrics) in numbered order are as follows:

(1) Barge tonnage passing through each lock over time
(2) Annual barge tonnage with origin and destination within the Ohio River navigation system
(3) Annual barge tonnage with origin in the system but moved out of the system
(4) Annual barge tonnage with origin outside the system but moved into the system
(5) Percentages of different commodities transported along the river over time
(6) Numbers of terminals and intermodal transfer facilities over time
(7) Average queuing times for barge traffic at locks over time
(8) Capacity and condition of rail and highway links in the study area and
(9) Amount and types of fuel used by tows over time.

10.12 CONCLUSIONS

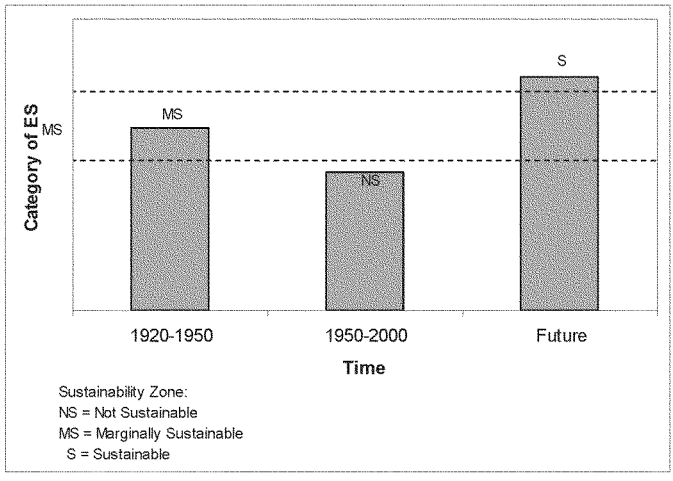
Based upon the above-described historical information, the actions and effects, the three features (or indicators) of ES of transportation and traffic, transportation and traffic sustainability can be characterized and depicted in **Figure 10-6** as follows:

- In the time period prior to 1920, and continuing up to about 1950, the waterway transportation and traffic system can be classified as "marginally sustainable." This classification is a result of system capacities that tended to exceed demands; however, the system was not particularly cost-effective or efficient, nor was it focused on minimizing externalities.

- In the time period from 1950 to 2000, "non-sustainable" conditions were often experienced as a result of construction of new infrastructure, demands that exceeded system capacities at numerous locations, and necessary use of auxiliary locks during repair and maintenance periods.

- Due to the aging infrastructure, it can be anticipated that "non-sustainable" conditions will continue into the future, and even further decline, in the absence of the system investment plan and its implementation. However, it is anticipated that sustainability of the transportation and traffic system will improve as a result of navigation investment actions.

FIGURE 10-6
ES of Transportation and Traffic System



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Chapter 11
SOCIOECONOMIC EFFECTS

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11.2 DEFINITION OF RIVER-RELATED SOCIOECONOMIC IMPACTS

Socioeconomic Resources (SR) are related to human communities in the Cumulative Effects Assessment (CEA) planning context. The National Environmental Policy Act (NEPA) provides the basic national charter to assess and mitigate impacts to human communities, neighborhoods, cultural groups, and others. These "social impacts" have been defined in federal guidance issued by the U.S. Department of Commerce, NOAA, as "the consequences to human populations of any public or private actions – that alter the ways in which people live, work, play, relate to one another, organize to meet their needs and generally cope as members of society. The term also includes cultural impacts involving changes to the norms, values, and beliefs that guide and rationalize their cognition of themselves and their society" (Interorganizational, 1994).

The above guidance goes on to define social impact assessment "in terms of efforts to assess or estimate, in *advance*, the social consequences that are likely to follow from

specific policy actions (including programs, and the adoption of new policies), and specific government actions (including buildings, large projects and leasing large tracts of land for resource extraction), particularly in the context of NEPA." (Interorganizational, 1994)

Environmental Justice (EJ) addresses the issue of disproportionate impacts on minority and economically disadvantaged populations. Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations," provides that "each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations (EO 12898)."

11.3 OBJECTIVES AND SCOPE OF THE SOCIOECONOMICS STUDY

11.3.1 Objectives

This chapter assesses the system-wide cumulative SR and EJ impacts of all likely major navigation improvements along the mainstem of the Ohio River from 2000 - 2070. SR and EJ impacts that are directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and Reasonably Foreseeable Future Actions (RFFA) by the US Army Corps of Engineers (Corps) and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFAs. These future actions include the major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, actions by non-governmental entities, and predictions of general economic expansion and development.

The results of the CEA are intended to contribute to two topics of subsequent public debate: (1) whether the impacts of the RFFAs constitute acceptable outcomes for the affected resources and (2) how the proposed navigation improvements contribute to those outcomes.

11.3.2 Geographic Scope

The geographic focus for SR impacts includes those areas most directly impacted by operation and maintenance of the navigation system. In order to reflect influences of the navigation system in the context of broader business and economic forces, as well as to maintain consistency with the scope of other chapters (Land Use, Health and Safety), counties adjacent to the Ohio River mainstem are defined as the geographic focus for SR impacts. Where such counties are part of a Census-defined Metropolitan Statistical Area (MSA), all counties in the MSA are included in the geographic focus for SR impacts.

11.3.3 Time Frame

The established time frame for this project is 1920 to 2070. The earlier date approximates the initiation of modern Corps lock and dam construction activities on the Ohio River. The latter date approximates the end of the 60-year planning horizon encompassed by the Ohio River Main Stem Study (ORMSS).

11.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during Summer 2001 in communities along the Ohio River. The meetings created opportunities for the public, state and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. More detailed discussions of the scoping meetings are presented in Exhibits A & B.

185 people attended the meetings and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted. Comments that directly or indirectly addressed SR or EJ issues are presented in **Table 11-1**. Some of the comments listed below incorporate issues that are more completely addressed in the 'Health and Safety' or 'Transportation and Traffic' chapters.

TABLE 11-1
Comments from Public Scoping Meetings

Direct Comments on Socioeconomic Impacts or Environmental Justice Issues	Total Comments	Impact[1]
Loss of shoreline trees and river property caused by barge activity	7	-
Bank undercutting & failure caused by increased barge traffic & queuing and wave action	7	-
Potential adverse effects of higher pool elevations on bridges, other infrastructure and property	6	-
Trash increasingly becoming a problem for property owners and river users	6	-
Reliability of barge traffic forecasts	5	Q
ORMSS schedule possibly lagging behind future navigation needs	5	-
Mouths of tributaries silted in, impairing fish habitat, limiting access and damaging property	5	-
Loss of green space & wildlife habitat with development of marina facilities	5	-
Need more public access ramps in each pool to reduce recreational crafts' usage of locks	5	R-M
Possibility of developing hydroelectric power at dams	5	+/-
Development of floodplains & wetlands resulting in increased runoff and habitat loss	4	-
Loss of significant farmland to urban development along river corridor	3	-
Need to develop comprehensive plans for development along river	3	R-M
Navigation structures presently not keeping pace with traffic demands	3	-
Bank erosion caused by USACE-controlled pool fluctuation	3	-

Direct Comments on Socioeconomic Impacts or Environmental Justice Issues	Total Comments	Impact[1]
Health and safety concerns related to increased traffic and development	3	-
Role of USACE related to litter and debris in river, especially at locks and dams	3	Q
Procurement and control of land by the federal government	3	+/-
Restrictions placed on property owners participating in federal programs	2	+/-
Interest by Ohio to promote Ohio River as a vacation destination	2	+
Degradation of recreational value of river caused by increased industrialization	2	-
Increased development of scenic byways and bikeways	2	+
Accuracy of models for predicting population growth & development	2	Q
Importance of including commercial dredging & associated permitting process in CEA	2	R-S
Challenge to water quality presented by CSOs and SSOs	2	-
Impaired water quality & bioaccumulation in fish tissue of harmful substances stirred up by dredging.	2	-
Importance of maintaining shipping channel	2	+
Pools maintained at higher level than agreed on in flowage easement contracts with property owners	2	-
Concern that landowners must sell at USACE's price for OR Islands National Wildlife Refuge	2	-
Enhancement of river transportation capabilities through corresponding development/improvement of intermodal transportation facilities	2	+
Need to integrate navigation with other transportation modes	2	R-M
Need for long-range coordination with FHWA , state & local transportation agencies	1	R-M
Study may overemphasize transportation and river commerce	1	-
Reliability of barge traffic forecasts	1	Q
Why USACE expects only 1% increase in barge traffic, while a 3% increase in gross domestic product is expected	1	Q
OH Division of Watercraft receives many complaints about barges damaging shoreline near Greenup L/D	1	-
Overall effects of navigation structures and activities on groundwater levels	1	-
Need to protect public groundwater supplies.	1	R-M
Need for long-term plan to address silt removal and prevent future sedimentation	1	R-M
Potential partnering with private enterprise to remove marketable aggregates when dredging	1	+
Habitat damage caused by Corps permitted commercial sand and gravel dredging	1	-
Shoreline instability threatening costly restoration projects in wildlife management areas	1	-
Severe erosion occurring at Slough Wildlife Mgmt. Area (downstream from Henderson, KY)	1	-
Need for elevation management to prevent water levels from exceeding flood stage	1	R-M
Effects on recreation and quality of life of raising Montgomery pool level	1	-
Economic impacts if pool elevations change	1	-
Increase in barge loading/unloading facilities limiting fishing access from shore	1	-
Danger to recreational users of submerged trees toppled by bank erosion	1	-
Suggestion of greater use of levees for passive recreation	1	R-M
Effects on recreation and heritage sites in Illinois, including Tower Rock Recreation Area	1	-
Include recreational facilities as design components of L/D revitalization	1	R-M

Direct Comments on Socioeconomic Impacts or Environmental Justice Issues	Total Comments	Impact[1]
& construction projects		
Need for long-term plan for replacement & maintenance of existing recreational launch ramps	1	R-M
Need more access ramps in each pool for emergency response and boating safety officials	1	R-M
Potential application of eminent domain in the Ecosystem Restoration Program	1	Q
Need for eminent domain in restoration of Ingram Island	1	R-M
Cumulative effect of discharges to river may offset water quality improvements.	4	-
Damage/destruction of mussel beds and fish spawning areas	4	-
Changes in shipping demand as low sulfur coal reserves near depletion in next 25 years	2	+/-
Possible trash hauling by barges in the future	2	+/-
Possible use of dredge spoils to improve riparian or island habitat or for upland filling	2	+/-
Need for fish habitat improvements, including fish passages around locks and dams	2	R-M
Loss of wildlife corridors as shoreline develops	2	-
Loss of unique, sensitive species due to water quality problems and habitat modifications	2	-
Potential instability of OR islands & futility of creating islands wildlife refuge	2	-
How ORMSS study will affect Greenup L/D upgrade	1	Q
Need for ORMSS to address livability issues of 2-for-3 (EMD) plan	1	R-S
View of navigation improvements as benefiting only shipping industry	1	-
High levels of mercury, arsenic, fecal coliform bacteria and agri-chemicals in surface water	1	-
Importance of coordination between USACE and OR public water suppliers	1	R-M
Importance of continued water quality improvements as a high priority	1	R-M
Stress and disruption of waterfowl migratory patterns caused by barge traffic	1	-
Riverfront development constraints related to endangered species	1	-
Need to prevent distribution of exotic /invasive plants and animals through USACE actions	1	R-M
Impairment of scenic value of river corridor for millions of people living in the Ohio Valley	1	-
Consideration by USACE of set-aside amount and other enhancements separate from mitigation	1	R-M
Effects on 4 Wild & Scenic Rivers proposed for Illinois	1	-
Need for adequate financial resources to complete the mitigation requirements within the 401 certification program	1	R-M

[1]Impact codes:
"+, -, +/-" Comments that suggest positive, negative or mixed impacts to the socioeconomic environment.
"R-M, R-S" Comments recommending an action for management of river resources (M) or as a topic in the CEA study (S).
"Q" General questions.

11.5 INDICATORS OF SUSTAINABILITY

Socioeconomic Effects (SE) can occur as a result of job creation and/or population relocations to new areas. Further, secondary consequences result from new jobs created to meet infrastructure and service needs of new populations. On the negative side, closure of

old industrial plants causes job losses and declines in economic indicators in local areas. Unique SR effects can occur during major construction projects involving construction workers moving into local areas.

Numerous business and economic forces influence population growth or loss and related economic changes along the Ohio River mainstem. The navigation system and its associated economic influences is only one such force in the overall socioeconomic characteristics of the area. The navigation system has been in existence for many decades, and the types and levels of product movement within the system are fairly stable. Other than small annual percentage changes, no major changes are anticipated.

There are numerous indicators of SR; for purposes of this study, the following are used: (1) total population, (2) minority population, (3) economically disadvantaged population, (4) Indian tribes and their populations, (5) economic indicators such as per capita incomes, households in poverty, etc., and (6) employment levels by SIC code and unemployment rates (or levels).

Information on the above indicators is available through the U.S. Bureau of the Census, Bureau of Economic Analysis (BEA) and commercial sources. Data on some factors go back to 1900 or earlier and this information is generally available at the county-level.

The primary indicator of SR sustainability used in this chapter is the baseline county-level projection of populations for Ohio River states prepared by the economic consulting firm NPA Data Services (NPA, 1999). NPA's key forecasting assumptions involve several demographic and economic variables. The demographic variables are fertility, mortality, and immigration rates. The economic variables are labor force participation and growth of national productivity, or product Gross Domestic Productivity (GDP) per worker. Fertility and mortality rates are taken from Census Bureau forecasts published in 1996 (Report P25-1130). In the baseline scenario, the Census Bureau's middle series fertility and mortality rates are used.

11.6 LAWS, REGULATIONS, ORDINANCES, AND PROGRAMS

11.6.1 Legal Mandates

The Dept of Commerce "Guidelines and Principles for Social Impact Assessment" includes the following discussion of legal mandates. Although NEPA created requirements for the assessment of impacts to the human environment, initial direction was somewhat vague. Subsequent regulations from CEQ stated that the "human environment is to be interpreted comprehensively to include the natural and physical environment and the relationship of people with that environment" (CEQ, 1986 (40 CFR 1508.14)). Agencies need to assess not only so-called "direct" effects, but also "aesthetic, historic, cultural, economic, social, or health" effects, "whether direct, indirect, or cumulative" (40 CFR 1508.8).

The CEQ Regulations also note that "economic or social effects are not intended by themselves to require preparation of an environmental impact statement" (40 CFR 1508.14). However, when an EIS is prepared "and economic or social and natural or

physical environmental effects are interrelated, then the EIS will discuss all of these effects on the human environment" (40 CFR 1508.14). The EIS is thus intended to provide a kind of full-disclosure procedure for federal decision-makers, who are then expected to consider the negative as well as the positive implications of potential courses of action, and the unintended as well as the intended consequences, before they proceed.

NEPA also provides citizens with the opportunity to challenge agency decisions; again in this case, however, NEPA's provisions are often misunderstood. The greatest level of legal vulnerability for the agency is *not* created by taking actions that will create negative impacts. It comes from failing to consider or fully analyze those impacts in advance (Interorganizational, 1994).

11.6.2 Agency Guidelines

Numerous federal agencies have published guidelines addressing SR issues, EJ, or both topics. Guidance from the General Services Administration (Fact Sheet, GSA) notes that "NEPA provides a major planning context in which EJ issues can be addressed, though such issues should be considered under other environmental review authorities as well (e.g., the National Historic Preservation Act and the Endangered Species Act). The Presidential Memorandum (EO 12898) identifies four important ways to consider EJ under NEPA, which are summarized in the CEQ's EJ guidance (CEQ 1997) as follows:

- "Each Federal agency should analyze the environmental effects, including human health, economic, and social effects of Federal actions, including effects on minority populations, low-income populations, and Indian tribes, when such analysis is required by NEPA.

- Mitigation measures identified as part of an environmental assessment (EA), a finding of no significant impact (FONSI), an environmental impact statement (EIS), or a record of decision (ROD), should, whenever feasible, address significant and adverse environmental effects of proposed Federal actions on minority populations, low-income populations, and Indian tribes.

- Each Federal agency must provide opportunities for effective community participation in the NEPA process, including identifying potential effects and mitigation measures in consultation with affected communities and improving the accessibility of public meetings, crucial documents, and notices.

- Review of NEPA compliance (such as EPA's review under Section 309 of the Clean Air Act) must ensure that the lead agency preparing NEPA analyses and documentation has appropriately analyzed environmental effects on minority populations, low-income populations, or Indian tribes, including human health, social, and economic effects."

CEQ's guidance outlines six principles that should be addressed in the course of NEPA review to ensure consideration of EJ, which can be paraphrased (from Fact Sheet, GSA) as follows:

- Consider the human composition of the affected area - that is, its population and how it is used by human communities, and determine whether any such communities are characterized by low-income levels or high-minority composition. If so, determine whether there may be disproportionately high and adverse effects on such populations.

- Consider not only direct impacts on the health and environmental quality of EJ communities, but indirect, multiple, and Cumulative Effects (CE) as well, including effects that are not within the control of or subject to discretionary actions of the reviewing agency.

- Recognize that the cultural, social, occupational, historical, and economic characteristics of an EJ community may amplify the environmental effects of an action. Such a population may be more sensitive to such effects and less resilient in adapting to them, than another community.

- Implement effective public participation strategies that seek to overcome linguistic, cultural, institutional, geographic and other barriers to meaningful participation, and that include active outreach.

11.6.3 Laws, Regulations, Ordinances, and Programs

Virtually every law, regulation or program addressing the development or management of public resources can be interpreted as having a social impact component. **Table 11-2** lists regulatory actions of significance to Corps activities that include specific reference to public (or state/local) participation in agency decision making or that mandate attention to differential impacts of program activities. Other regulatory actions with specified social impact objectives are listed in the Health and Safety, Recreation, and Transportation and Traffic chapters.

TABLE 11-2
Laws, Regulations, Ordinances, And Programs Relevant to Social Impacts and Environmental Justice

Law/Program	Key Components	Relevance to Socioeconomic Issues or Environmental Justice
National Environmental Policy Act (NEPA), 1970	• Requires preparation of environmental impact assessments for new construction projects by private and governmental agencies • Includes federal government's responsibility to assess the social impact of proposed actions.	Provides basic national charter to assess and mitigate impacts to human communities, neighborhoods, cultural groups and others.
U.S. Council on Environmental Quality (CEQ), 1976 (40 CFR 1500-1508). Also, 1986 re-issue of regulations.	• Regulations for implementing NEPA procedural provisions. • "Human environment" shall be interpreted comprehensively to include the natural and physical environment and the relationship of people with that environment.	Regulations addressing implementation of NEPA. 1986 re-issue clarified treatment of incomplete or unavailable information.

Law/Program	Key Components	Relevance to Socioeconomic Issues or Environmental Justice
Emergency Planning and Community Right-To-Know Act of 1986 and Pollution Prevention Act of 1990	• Provides citizens, local governments, and response authorities with information regarding potential hazards in their community. • Requires emergency planning, mandates reporting, designates local authorities as recipients of information.	Designated to promote emergency planning and preparedness at both the state and local level.
Corps' Permitting Statutes (U.S. Army Corps of Engineers)	• Section 10 of Rivers and Harbors Act (1899) prohibits the unauthorized obstruction or alteration of any navigable water of the United States. • Section 404 of CWA authorizes the Corps to issue permits for the discharge of dredged and fill materials into waters of the U.S..	Permits require assessment of impacts on water quality, aquatic ecological resources, socioeconomics; and mandate mitigation of adverse impacts
Farmland Protection Policy Act	• Minimize federal actions contributing to unnecessary and irreversible conversion of farmland to nonagricultural uses. • Assure federal compliance with state and local farmland protection initiatives.	Protects economy and culture of rural communities.
Federal Water Project Recreation Act	• Establishes policy to consider opportunities for outdoor recreation and fish and wildlife enhancement planning of any Federal navigation, flood control, reclamation, hydroelectric or multi-purpose water resource project. • May include recreation & wildlife benefits in project cost/benefit analysis.	Requires non-federal partners to cost-share, operate and maintain recreation, wildlife enhancement facilities.
Fish and Wildlife Conservation Act	• Act declares that fish and wildlife are of ecological, educational, esthetic, cultural, recreational, economic and scientific value to the Nation.	May provide financial and technical assistance to States to conduct inventories and conservation plans for non-game wildlife.
Fish and Wildlife Coordination Act	• Act recognizes contribution of wildlife resources to Nation, increasing public interest and significance due to expansion of national economy and other factors. • Provides that wildlife conservation receive equal consideration and be coordinated with other features of water-resources development programs.	Corps shall consult with U.S. Fish and Wildlife Service (FWS), National Marine Fisheries Service (NMFS) as appropriate, and state wildlife resource agencies.
Flood Control Act of 1944	• Authorizes the Corps, to construct, maintain and operate public park and recreational facilities at water resources development projects (includes non-reservoir projects). • Local interests also permitted to construct, operate and maintain such facilities	Water areas of all such projects shall be open to public use for general recreational purposes, includes public access.

Law/Program	Key Components	Relevance to Socioeconomic Issues or Environmental Justice
Executive Order 12898 Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations	• Directs Federal agencies to address disproportionately high and adverse human health or environmental effects of agency programs, policies, and activities on minority populations and low-income populations.	Includes provisions for assisting disadvantaged group's participation in agency decision making.
Title VI of the Civil Rights Act of 1964	• Requires agencies to ensure effects of actions are nondiscriminatory.	Similar to EJ, but generally required action by affected groups to address impacts.

11.7 PAST TO CURRENT BASELINE CONDITIONS

Discussions of past to current conditions that may also be pertinent to SR concerns are presented in other VEC chapters. Exhibit D, Land Use, included a summary of historic studies recently funded by the Corps, reviews of current land use patterns and trends in the Ohio River Valley, and population trends and projections for counties adjacent to the Ohio River. Chapter 8, Health and Safety, addressed spills of fuel, oil, and other contaminants on or along the Ohio River, boating accidents, bacteriological contamination of water quality, and fish consumption advisories. See also the Cultural Resources, Transportation and Traffic, and Recreation chapters for additional discussion of baseline conditions relevant to SR concerns.

11.7.1 Economic Benefits of the Ohio River Navigation System

Historic settlement and development patterns were summarized in **Exhibit D**, Land Use. That discussion noted the rapid construction of railroads in the Ohio Valley between 1850 – 1860 and the subsequent decline of canals, river transportation, and some cities. While canals were relatively quickly and completely displaced by the railroads, impacts to river transportation were more gradual and never resulted in complete displacement of commercial traffic on the Ohio River. Steamboat construction in Cincinnati, for example, declined only slightly during the 1850s, and the cheaper cost of water transportation combined with the opening of other markets farther west where the railroad had yet to penetrate meant that the long-term effects of the railroads on river commerce took a while to be fully realized (Muller 1972: 346).

However, the railroad's ability to operate year round was a significant advantage over the seasonal and sometimes unpredictable fluctuations of river borne commerce. The railroads also improved their competitiveness by offering steeply discounted freight rates during the 1850s. As a result of these and other factors, rail lines increasingly came to dominate the transportation of Upper and Middle Ohio Valley agricultural produce to national markets and the movement in merchandise and manufactured goods moving the other way (Muller 1972: 343).

The lack of much additional rail expansion in Ohio by 1860 also meant that cities were largely "stuck" with the network that had evolved quickly during the 1850s. This benefited some Ohio River cities, but towns without rail service were largely dependent for commerce on whatever could be brought in or shipped out in the slowly diminishing river trade. Overall, the effect of the railroads on Ohio River towns was beneficial if the town was selected as a railroad throughway or terminal. Even so, the railroads gave increased economic importance to newer inland towns located well away from the river and re-directed the movement of trade. River towns were no longer the only "players" on the urban scene (Muller 1972: 341-342).

While the role of the Ohio River in shaping early settlement and development patterns is broadly recognized, the emergence of railroads in the mid-nineteenth century has tended to overshadow the economic contributions of the Ohio River navigation system during the twentieth century. Construction of the initial navigation system between 1904 and 1929 occurred at a time when commercial river traffic in general was falling off due to the combined impact of the railroads and the subsequent emergence of the nation's highway system. The appearance and growth of these forms of transportation—both of which have had major effects on urban life in the river valley—also have acted to blur recognition of the continuing but "lower amplitude" contribution of river commerce to contemporary urban life, especially in the cost-effective transport of bulk commodities such as coal and steel products, petroleum, and chemicals. The contributions of the river and its navigation system thus have been largely overlooked.

Completion of the navigation system resulted in the availability of dependable year-round transportation in a nine-foot channel from Pittsburgh to Cairo. The demands of World War I contributed to a rediscovery of the capabilities of the improved system and cargo shipments began to increase from 1917 and continued increasing through the 1920s. Commercial towing companies and related construction, maintenance, and repair facilities became an important part of the valley economy and have remained such (Blagg, p. 14).

After the Second World War, the Ohio Valley enjoyed an economic boom that was based on the low cost of moving bulk goods on the river and the region's low electric power costs, which were due in large part to the same factor. Between 1946 and 1953 some 2500 new industrial plants were built in the Ohio Valley on or near navigable streams, an investment of approximately $5.5 billion (Bigham 1991:165). Steam electric plants in the region grew because of the advantages of cheap transportation of coal by water from both the Appalachian and lower Ohio fields. The ability to move large quantities of petroleum, coal, sulfur, and other raw materials led to the expansion of the chemical industry at Calvert City, Kentucky, near Paducah. In 1951 General Electric chose Louisville for the site of its huge Appliance Park plant. One of Louisville's advantages was its ability to receive steel from Pittsburgh by water year round. Alcoa chose Evansville for a major smelter in 1957 due to water transportation and cheap electricity. A number of metal, especially aluminum, fabricating firms have located manufacturing facilities along the Ohio in Hancock County, Kentucky for the same reason. While river transportation has not been a major source of direct employment for some time, its indirect impact on employment, and thus economic and population growth, became more important after World War II.

One of the few specific studies of the economic benefits of the Ohio River Navigation System was conducted by Joseph R. Hartley (Hartley 1959). Hartley found that river shipping had experienced a dramatic decline in the late nineteenth and early twentieth centuries due to the national growth of railroads and, beginning in the 1920s and 1930s, to the development of long-haul trucking. However, inland river shipping had made a significant comeback, growing from 20 billion ton-miles in 1939 to 120 billion ton-miles in 1957. Barge tonnage carried on the Ohio River in 1957 actually was larger than that on the Mississippi River if coastal traffic on the Lower Mississippi River was excluded (81.6 million tons vs. 74.6 million tons on the Mississippi). Hartley also was encouraged by the 9.5 percent annual growth rate in the number of ton-miles carried on the Ohio and its tributaries, rising from 1.5 billion ton-miles in 1929 to 17.2 billion ton-miles in 1957. Most of this consisted of coal and coke (32.9 percent of ton-miles and 54.7 percent of tonnage in 1957) followed by petroleum (34 percent), iron and steel (19.9 percent), chemicals (7.6 percent), and other commodities (5.6 percent). Actual tonnage had increased from just 22 million tons to 81.6 million tons over the same period.

The reasons for this dramatic traffic growth on the Ohio River system included:

- Technological developments in barge design, construction and method of towing
  - Steel barges supplanted wooden barges
  - Integrated tows permitted joining up to 30 barges in a single tow
  - Tow boats installed radar and adopted diesel engines
- Construction of the system of locks and dams by the U.S. Army Corps of Engineers
- Water transportation rates compared favorably to railroad rates
- In 1957, water-borne commerce averaged 0.4 cents/ton-mile, versus 1.4 for rail
- Transportation cost savings were passed on to shippers and consumers.

Hartley also concluded that transporting coal on the Ohio River to industrial consumers, many of them electrical generating plants built on the river flood plain, had kept the cost of both coal and electrical power down for millions of ultimate consumers. Ohio River electrical plants, Hartley discovered, were producing about 12 percent of the nation's electrical supply in 1957, up from 6 percent in 1939. River transportation of coal to these plants allowed them to save nearly one-third the cost of production when compared with the national average. Since these electrical generating plants also were developing transmission lines to towns and cities within 100-150 miles of the river, the benefits of cheaper electricity was being shared with urban centers far removed from the Ohio River itself (Hartley 1959: III).

In sum, by the mid-1950s, development of the Ohio River Navigation System had helped to sustain lower costs for delivered coal, had provided cheap but reliable water supplies, and had lower prices for steel and other industrial transportation. These economies, in turn had helped to keep down energy prices and the cost of steel-using durable goods (such as automobiles, stoves, and refrigerators) for individual consumers. River transportation also had boosted the prospects of the aluminum smelting industry and the chemical industries in the river valley. Prices for refined oil and petroleum products used in the rapidly growing number of automobiles now being driven on the nation's expanding interstate highway system were held down by lower cost barge transportation.

Although the cost benefits of river transportation radiated outward to the nation as a whole, Hartley found that the Ohio River Valley had benefited directly from increased industrial investment, job growth, greater per capita income, higher retail sales, and urban growth. The last three categories were higher in the Ohio River Valley than for the nation as a whole even though, Hartley concluded, the overall prosperity of the Ohio River Valley still lagged behind the rest of the country. In general, Hartley (1959: IV) concluded, "Improvement of the River has helped provide an economic base for healthy, sustained, and rational economic growth."

Many of the patterns of economic activity observed by Hartley 44 years ago remain today. Coal utilities in the Ohio River Valley still account for about 12 percent of national energy production, and the majority of that coal is moved by barge on the Ohio River system. Coal for industrial power production, petroleum products, chemical feedstock, and iron and steel commodities each account for about 5 percent of annual tonnage moved on the Ohio River.

11.7.2 Population History and Projections

Population history and projections for each county along the Ohio River were obtained from the 1999 National Economic Projection Series (NPA Data Services, 1999). This study provides three alternative growth projections of U.S. population and the economy at the national and regional levels over the period 1997-2050. The alternatives include a baseline or mid-range scenario and high and low growth scenarios intended to produce projections near the limits of plausibility. Population projections for the baseline scenario are presented in this report. These can be compared to population trends and projections based on Census Bureau data (including the 2000 Census) presented in Exhibit D, Land Use.

The baseline scenario follows middle series fertility and mortality assumptions of Census Bureau projections published in 1996 (Report P25-1130) and based on actual data for the years through 1994. These Census assumptions were modified by NPA Data Services, Inc., to conform to actual birth and death experience of the U.S. through 1997. The baseline scenario assumes the number of foreign immigrants per 1,000 population will continue to increase at the rate of 1.4 percent per year through the year 2025. This conforms to the actual rate of increase from the mid 1960s through the mid 1990s. After 2025, the number of immigrants is projected to rise only with population. U.S. labor force participation for civilians 16 and older in the baseline increases from a rate of about 0.67 in 1997 to about 0.71 by 2016, and thereafter diminishes to 0.59 by 2050. Productivity or Gross Domestic Productivity (GDP) per worker increases at an annual rate of 1.16 percent between 1997 and 2025, and thereafter grows at a rate of 1.12 percent between 2025 and 2050.

As a result of these assumptions, the total population of the U.S. is projected to grow at the annual rate of 0.87% from 1997 to 2025 and at 0.65% from 2025 to 2050, averaging 0.8 percent per year over the entire projection period. For the six-state region, annual population growth averages 0.32% through 2025 and 0.38% through 2050. For the 82 counties in the Ohio River region, population is projected to grow at an average annual rate of 0.31% through 2025 and 0.39% through 2050. The estimated population of 7,341,000 for the Ohio River region in year 2000 is projected to reach 7,911,000 by 2025 and

8,696,000 by 2050. These projections for the Ohio River region and sub-areas including the Metropolitan Statistical Area (MSA) are presented in **Table 11-3.**

TABLE 11-3
Population Projections for Ohio River Region and Sub-areas

(population = table entry x 1,000)									
	1970	**1980**	**1990**	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Pittsburgh MSA	2,792	2,683	2,504	2,467	2,428	2,447	2,499	2,541	2,588
Steubenville-Weirton MSA	167	163	142	137	129	126	125	125	126
Wheeling MSA	183	185	159	155	147	143	143	143	144
Parkersburg to Wheeling	53	59	52	52	51	51	52	52	53
Parkersburg-Marietta MSA	144	158	149	152	154	159	165	170	175
Huntington to Parkersburg	146	163	165	176	185	195	207	217	227
Huntington-Ashland MSA	308	337	312	317	320	328	339	350	360
Cincinnati to Huntington	133	149	143	150	157	167	178	188	197
Cincinnati CMSA	1,669	1,729	1,822	1,975	2,094	2,236	2,392	2,531	2,662
Louisville to Cincinnati	47	53	53	58	61	64	68	72	75
Louisville MSA	890	922	914	959	983	1,024	1,079	1,129	1,174
Evansville to Louisville	163	185	186	200	211	224	237	250	263
Evansville- Henderson-Owensboro MSA	334	363	367	385	395	410	429	447	465
Below Evansville	150	160	155	158	160	166	173	181	187
Totals	**7,179**	**7,309**	**7,123**	**7,341**	**7,475**	**7,739**	**8,087**	**8,396**	**8,696**
Source: NPA Data Services, 1999									

For sub-areas within the Ohio River region, the majority of projected population growth is concentrated within the established, major urban areas and is heavily influenced by population trends from 1967 to 1997. The Cincinnati Consolidated Metropolitan Statistical Area (CMSA), which showed strong growth during the previous 30 years, is projected to grow by almost 35% through 2050, reaching a population of 2,662,000. By contrast, the Pittsburgh MSA, which lost population during the previous 30 years, is projected to continue losing population through 2010. It is then projected to gradually gain population, reaching a total of 2,588,000 by 2050. However, the net growth of 121,000 for the Pittsburgh area (for 2000 to 2050) still accounts for about 9% of total growth in the region. Significant growth also is projected to occur in the Louisville and Evansville-Henderson-Owensboro MSAs, while the Huntington-Ashland MSA grows at a rate slower than the regional average. These 5 MSAs, representing 38 of the 82 counties and 83% of the year 2000 population, are projected to account for about 84.6% of total population growth in the region. Population projections for these MSAs are presented in **Figure 11-1**.

Population growth, or lack of growth, in other sub-areas also reflects past trends. The 12 county region on the upper Ohio River from Steubenville to Parkersburg is expected to experience almost no net growth through 2050. Modest growth in the Parkersburg MSA will be offset by continued population declines in the remainder of the

area. By contrast, non-MSA counties between Huntington and Parkersburg, Cincinnati and Huntington, Evansville and Louisville, and below Evansville are expected to grow by about 30% through 2050. These trends are illustrated in **Figures 11-2 and 11-3**.

FIGURE 11-1
Population Projections for Major MSAs

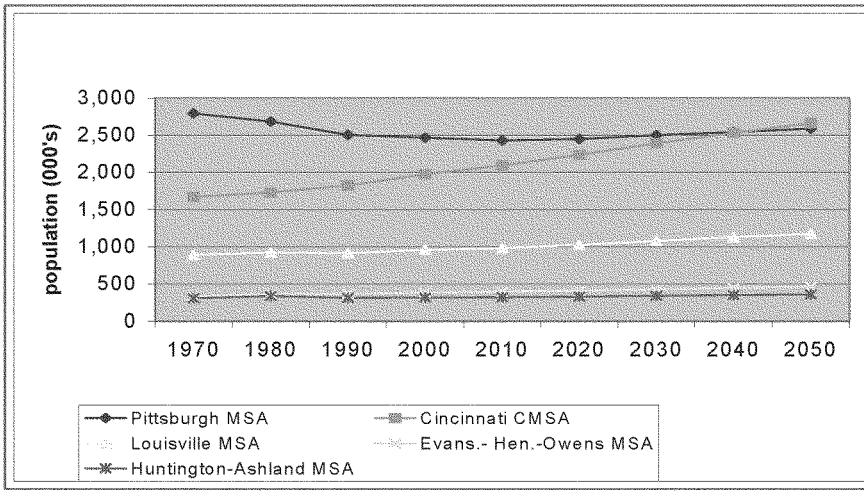


FIGURE 11-2
Population Projections for Upper River Sub-areas

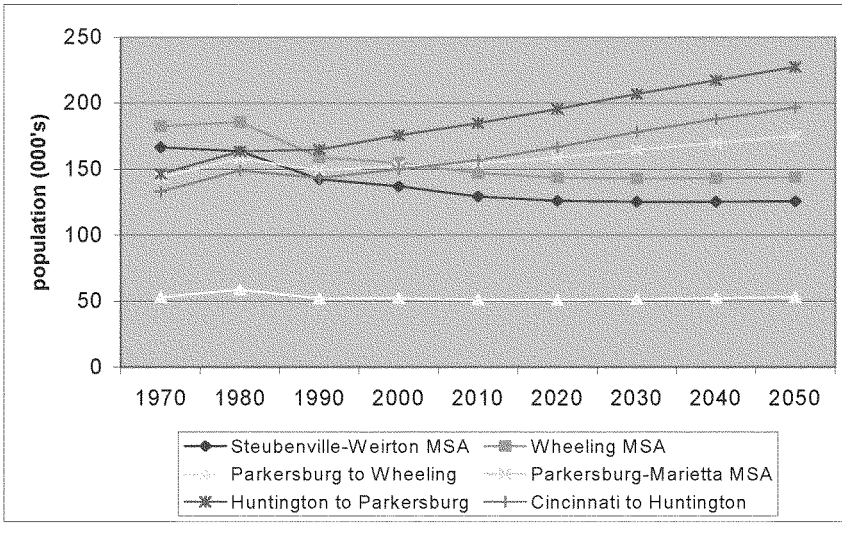
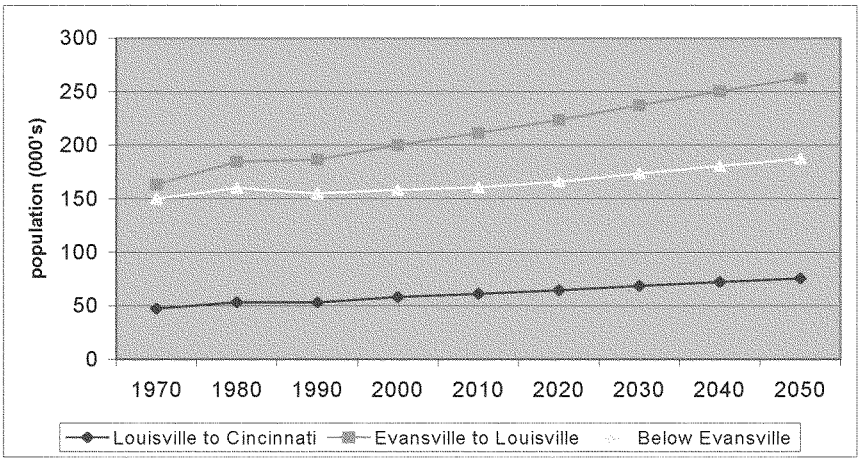


FIGURE 11-3
Populations Projections for Lower River Sub-areas



Source for Figures 11-1 through 11-3: NPA Data Services, 1999

11.7.3 Minority Populations

The Ohio River region has very few counties that exceed state averages for minority populations. In many counties, the percent minority population is only 20 or 30 percent of the state average. Counties that do exceed the state average are generally metropolitan centers such as Cincinnati in Hamilton County, Ohio. Rural counties with above average minority populations include Pulaski County, Illinois; and Hardin, Mason, Meade, and Union Counties, Kentucky. **Table 11-4** lists state averages and all counties that equal or exceed the state average.

TABLE 11-4
Non-White Populations

	Percent Estimates				
County and State	**1960**	**1970**	**1980**	**1990**	**2000**
Indiana	5.9	7.2	8.8	9.4	14.2
- no Indiana counties exceed the state average					
Illinois	10.6	13.6	19.1	21.7	32.2
- Pulaski	36.2	34.4	33.5	33.1	34.1
Pennsylvania	7.6	9.0	10.2	11.4	15.9
- Allegheny	8.3	9.3	11.2	12.5	16.2
Ohio	8.2	9.4	11.1	12.2	16.0
- Hamilton	14.4	16.1	19.9	22.3	27.6
West Virginia	4.9	4.1	3.8	3.8	5.4
- Cabell	4.5	4.4	4.9	4.9	7.1
- Ohio	3.1	3.4	4.1	4.1	5.9

Percent Estimates					
County and State	**1960**	**1970**	**1980**	**1990**	**2000**
Kentucky	7.2	7.4	7.7	8.0	10.7
- Hardin	7.4	9.0	14.7	14.9	19.5
- Henderson	10.2	8.4	7.7	7.6	9.3
- Jefferson	12.9	14.0	16.8	18.1	23.6
- McCracken	10.9	10.4	10.5	10.6	13.8
- Mason	9.9	9.3	7.8	7.9	9.5
- Meade	5.0	6.4	9.0	12.5	8.7
- Union	9.1	18.0	18.9	16.0	15.6
Source: US Census Bureau.					
Definition: White. A person having origins in any of the original peoples of Europe, the Middle East, or North Africa. It includes people who indicate their race as "White" or report entries such as Irish, German, Italian, Lebanese, Near Easterner, Arab, or Polish.					

Census records were also searched for Native American populations. Through 1980, state and county records identified very few individuals who identified themselves as Native American. The 1990 and 2000 Census appear to be identifying slightly larger populations, which may be the result of more sensitive measuring procedures. **Table 11-5** lists state averages and all counties that exceed the state average.

TABLE 11-5
Native American Populations

Percent Estimates					
County and State	**1960**	**1970**	**1980**	**1990**	**2000**
Indiana	0.1	0.1	0.1	0.2	0.3
- Clark	0.1	0.1	0.1	0.2	0.3
- Crawford	0.1	0.1	0.4	0.3	0.4
Illinois	0.1	0.1	0.1	0.2	0.2
- Gallatin	0.0	0.1	0.1	0.1	0.7
- Pope	0.1	0.1	0.2	0.4	0.8
Pennsylvania	0.1	0.1	0.1	0.1	0.1
Ohio	0.1	0.1	0.1	0.2	0.2
- Adams	0.0	0.1	0.1	0.3	0.7
- Athens	0.1	0.1	0.1	0.3	0.3
- Gallia			0.1	0.1	0.4
- Meigs	0.1	0.1	0.1	0.2	0.3
- Scioto	0.1	0.1	0.1	0.5	0.6
West Virginia	0.1	0.1	0.1	0.1	0.2
- Pleasants	0.0	0.1	0.1	0.1	0.5
Kentucky	0.1	0.1	0.1	0.2	0.2
- Bracken	0.1	0.1	0.1	0.1	0.3
- Bullitt	0.0	0.1	0.1	0.2	0.3
- Hancock	0.0	0.1	0.1	0.2	0.3
- Hardin	0.1	0.2	0.3	0.4	0.4
- Lawrence	0.0	0.1	0.1	0.1	0.3
- Livingston	0.0	0.1	0.1	0.2	0.4
- Meade	0.1	0.1	0.2	0.4	0.6
- Trimble	0.0	0.1	0.1	0.3	0.4
Source: US Census Bureau.					
Definition: American Indian and Alaska Native. A person having origins in any of the original peoples of North and South America (including Central America) and who maintain tribal affiliation or community attachment.					

Census records for 1970, 1980, 1990 and 1995 were reviewed for people of all ages in poverty, based on Census definitions for the periods studied. **Table 11-6** lists counties in the Ohio River region with higher than average poverty rates, and **Figure 11-4** illustrates their locations. Counties were identified for occurrence of high poverty rates if the percent in poverty exceeded 1.5 times the state average or 1.5 times the regional average (average poverty rate for the six state region) for any two of the four periods measured. Counties that exceed twice the state or regional average are also noted. Note that statewide poverty rates for Kentucky and West Virginia in 1970 exceeded 1.5 times the regional average.

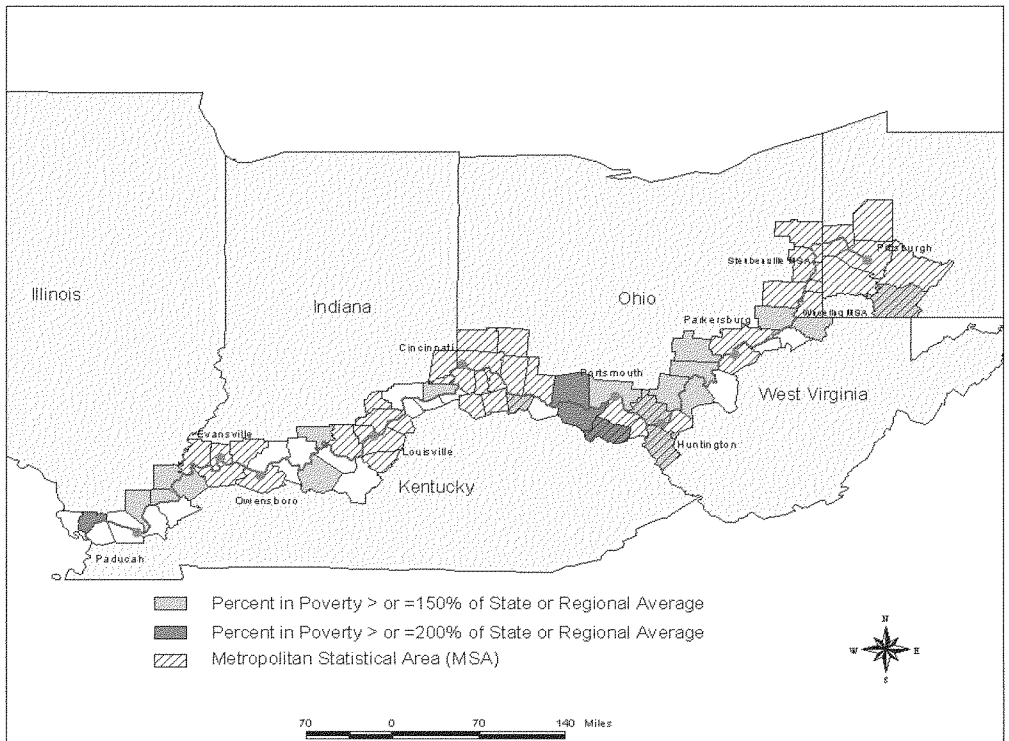
Table 11-6
People of All Ages in Poverty

	Percent Estimates			
State and County	**1970**	**1980**	**1990**	**1995**
Indiana	9.7	13.6	10.7	9.8
- Crawford	**21.5**	**25.4**	**18.5**	14.1
- Switzerland	**16.5**	**22.2**	15.2	13.4
Illinois	10.2	14.4	11.9	11.3
- Gallatin	**20.8**	**23.8**	**21.4**	**19.0**
- Hardin	**30.0**	**27.8**	**26.7**	**19.7**
- Pope	**39.9**	**27.6**	**25.2**	16.6
- Pulaski	**45.5**	**37.3**	**30.2**	**24.9**
Pennsylvania	10.6	14.6	11.1	11.4
- Fayette	**20.8**	21.0	**20.9**	
Ohio	10.0	14.0	12.5	11.3
- Adams	**31.6**	**24.7**	**28.5**	**20.3**
- Athens	**20.0**	**21.6**	**28.7**	**20.1**
- Gallia	**22.8**	14.9	**22.5**	**18.9**
- Lawrence	**20.2**	15.2	**23.5**	**19.9**
- Meigs	**23.9**	16.7	**26**	**21.4**
- Monroe	**18.1**	13.5	**21.5**	**17.4**
- Scioto	**20.5**	17.9	**25.8**	**21.4**
West Virginia	**22.2**	20.6	19.7	19.9
- Mason	**26.1**	18.7	**22.1**	20.2
- Wayne	**26.5**	**25.3**	**21.8**	**22.1**
- Wetzel	**21.4**	18.1	20.5	**20.7**
Kentucky	**22.9**	23.5	19.0	17.9
- Bracken	**28.9**	23.9	**21.4**	17.4
- Breckinridge	**24.8**	**29.7**	**23.2**	**20.7**
- Carter	**33.5**	**34.9**	**26.8**	**27.1**
- Lawrence	**45.0**	**37.9**	**36.0**	**30.9**
- Lewis	**31.1**	**39.7**	**30.7**	**28.1**
- Union	**27.8**	**27.1**	**22.1**	16.0
# counties > 1.5 state/regional avg.	**23**	**13**	**21**	**16**

Bold – exceeds 1.5 x state or regional average; **bold** – exceeds 2 x state or regional average.

Source: US Census Bureau, 1970, 1980, and 1990.
US Census 1995, http://www.census.gov/hhes/www/saipe/stcy.htm
Definition: Poverty http://www.census.gov/hhes/poverty/povdef.html

FIGURE 11-4 Ohio River Counties with High Poverty Rates



Per capita incomes provide an alternative to Census poverty rates for comparison of states, counties, and other subregions. Per capita incomes are calculated annually by the Bureau of Economic Analysis (BEA). For the six state region, the population weighted per capita income in 2002 represented 0.981 percent of the national per capita income. All states in the region show fairly stable maintenance of their income status relative to the national average, with four states gaining, Ohio essentially unchanged, and West Virginia showing slight decline. These rankings and trends are illustrated in **Table 11-7.**

TABLE 11-7
State Per Capita Income as % U.S. Average

State	2002 (rank/51)	Highest (year)	Lowest (year)	22 Year Trend
Illinois	1.080 (9)	1.100 (1997)	1.050 (1985)	+3.3%
Pennsylvania	1.025 (16)	1.025 (2002)	0.977 (1984)	+2.9%
Ohio	0.950 (26)	0.980 (1994)	0.944 (2001)	-0.15%
Indiana	0.913 (33)	0.940 (1994)	0.892 (1983)	+2.4%
Kentucky	0.827 (40)	0.827 (2002)	0.779 (1986)	+4.0%
West Virginia	0.766 (49)	0.793 (1982)	0.729 (1989)	-0.88%
Source: US Dept. of Commerce, Bureau of Economic Analysis http://www.bea.doc.gov/				

Individually, Illinois and Pennsylvania consistently rank among states with the highest per capita incomes, Ohio steadily represents the midpoint among states, and Indiana represents the point at which 2/3 of the states have higher per capita incomes. Despite significant gains for the past two decades, Kentucky remains in the bottom tier of states while West Virginia's declining incomes keep it very near the bottom for all states.

Per capita incomes for Ohio River counties and their geographic groupings are in **Figure 11-5** and in **Table 11-8**. For the 82 counties in the Ohio River region (counties adjacent to the river plus adjoining MSA counties), per capita incomes can be used to compare subareas of individual states or to illustrate the general income status of multi state groups of counties along the river. Counties can be grouped as upriver or downriver, with Cincinnati CMSA counties occupying the middle area between these groups.

Within the Ohio River region, 47 of the 82 counties (57.3%) have per capita incomes less than or equal to 75% of the national average. A total of 25 counties (30.5%) have incomes less than or equal to 67% of the national average. In general, upriver areas and non-MSA areas have a higher proportion of counties with below average per capita incomes. The Pittsburgh MSA area has only 2 of 7 counties below the 75% threshold, while in Cincinnati 5 of 13 counties have per capita incomes below 75% and 4 are below 67% of average. Between Pittsburgh and Cincinnati, all of the 13 non-MSA counties fall below 75% of average, with 9 falling below 67%. Among MSA counties between Pittsburgh and Cincinnati, 8 of 14 fall below 75%, with 3 of 14 below 67%.

Along the lower river, only one of the 12 MSA counties within Louisville, Evansville, Owensboro, or Henderson falls below 75% of the national average per capita income. Among the 22 non-MSA counties, 17 of 22 fall below 75% and 8 fall below 67%.

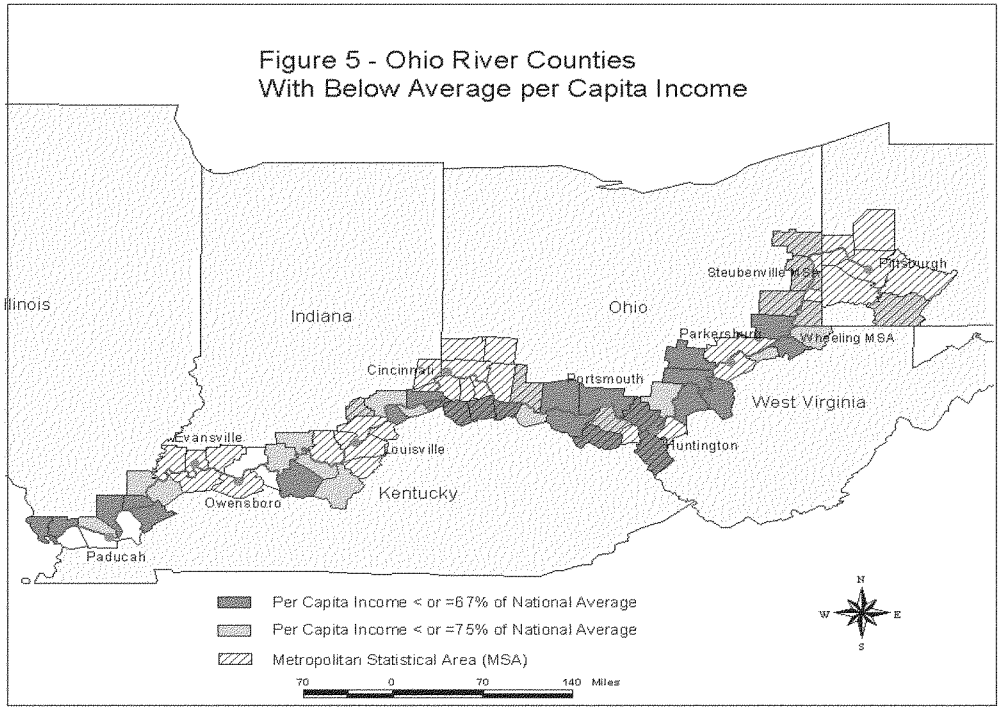
Counties with higher than average per capita incomes along the Ohio River are almost exclusively associated with major urban centers. Of the 5 counties with per capita incomes above the national average, 3 are the core counties for the cities of Pittsburgh, Cincinnati, and Louisville while 2 are adjacent counties within the MSAs of Cincinnati and Louisville.

TABLE 11-8
MSAs and Non-MSA Counties Adjacent to Ohio River

Pittsburgh, PA MSA	**Per Capita Income***		**Non-MSA Counties**	
Allegheny, PA	121			
Beaver, PA	88		All 7 PA counties are in	
Butler, PA	93		Pittsburgh MSA.	
Fayette, PA	75			
Washington, PA	99			
Westmoreland, PA	92			
Columbiana, OH	71			
Stuebenville-Weirton, OH-WV MSA	**Per Capita Income***			
Brooke, WV	75			
Hancock, WV	83			
Jefferson, OH	72			
Wheeling, WV-OH MSA	**Per Capita Income***		**Parkersburg to Wheeling**	**Per Capita Income***
Marshall, WV	68		Monroe, OH	63
Ohio, WV	93		Pleasants, WV	72
Belmont, OH	73		Tyler, WV	59
			Wetzel, WV	69
Parkersburg-Marietta, OH-WV MSA	**Per Capita Income***		**Huntington/Ashland to Parkersburg**	**Per Capita Income***
Washington, OH	76		Athens, OH	65
Wood, WV	81		Gallia, OH	75
			Meigs, OH	61
			Jackson, WV	67
			Mason, WV	62
Huntington-Ashland, WV-KY-OH MSA	**Per Capita Income***		**Cincinnati to Huntington/Ashland**	**Per Capita Income***
Cabell, WV	82		Adams, OH	62
Wayne, WV	54		Scioto, OH	67
Boyd, KY	85		Bracken, KY	60
Carter, KY	63		Lewis, KY	44
Greenup, KY	70		Mason, KY	73
Lawrence, OH	63			
Cincinnati, OH-KY-IN CMSA	**Per Capita Income***		**Louisville to Cincinnati**	**Per Capita Income***
Dearborn, IN	92		Jefferson, IN	74
Ohio, IN	77		Switzerland, IN	58
Boone, KY	99		Carroll, KY	73
Campbell, KY	87		Trimble, KY	54

Gallatin, KY	58			
Grant, KY	65			
Kenton, KY	95			
Pendleton, KY	63			
Brown, OH	73			
Butler, OH	94			
Clermont, OH	98			
Hamilton, OH	117			
Warren, OH	101			
Louisville, KY-IN MSA	**Per Capita Income***		**Evansville to Louisville**	**Per Capita Income***
Clark, IN	87		Crawford, IN	69
Floyd, IN	96		Perry, IN	75
Harrison, IN	81		Spencer, IN	83
Scott, IN	71		Breckinridge, KY	58
Bullitt, KY	78		Hancock, KY	85
Jefferson, KY	110		Hardin, KY	75
Oldham, KY	106		Meade, KY	74
Evansville- Henderson-Owensboro, IN-KY	**Per Capita Income***		Below Evansville	**Per Capita Income***
Daviess, KY	83		Alexander, IL	60
Henderson, KY	87		Gallatin, IL	71
Posey, IN	96		Hardin, IL	63
Vanderburgh, IN	98		Massac, IL	71
Warrick, IN	96		Pope, IL	59
			Pulaski, IL	60
			Ballard, KY	90
			Crittenden, KY	59
			Livingston, KY	78
			McCracken, KY	99
			Union, KY	71
Source: US Dept. of Commerce, Bureau of Economic Analysis ***Year 2001, as per cent of U.S. Average**				

FIGURE 11-5 Ohio River Counties with Below Average per Capita Income



11.8 INTERACTIONS WITH OTHER VALUED ENVIRONMENTAL COMPONENTS (VECS)

SR and EJ factors exhibit a high level of interaction with Land Use. Both subjects address past to present patterns, projections of population, settlement patterns, and economic indicators. SR also interacts strongly with Health and Safety, Recreation, Transportation and Traffic, and Cultural Resource VECs. These VECs address various community values that are reflected in the socioeconomic character of the region. Connectivity is less obvious between SR factors and the environmental resource VECs, although there is growing recognition of the contributions of natural systems functionality to the well being of human communities. VEC interactions are illustrated in **Table 11-9.**

TABLE 11-9
Interactions of Socioeconomic and EJ Factors with Other VECs

VEC	SR & EJ Factors & Impacts	Past/Present Trends	Future Trends	Comments
Land Use	Home ownership opportunities and expectations.	Traditional city/rural patterns replaced by suburban patterns.	Development consumes more acreage per capita.	EJ – limited alternatives if cannot afford 'conventional' housing.
Transport -ation & Traffic	Vehicle ownership opportunities and expectations.	Expanding highway network to accommodate traffic growth.	Continued growth of miles driven per capita.	EJ – limited alternatives if cannot afford personal vehicle.
Recreatio n	Expanding leisure time and disposable income per capita.	Growth of river oriented activity with improved water quality and accessibility.	Expanding variety of river-oriented activity. Potential conflicts from crowding or incompatible uses.	Potential continued growth of urban river-front oriented development (housing-shopping-recreation).
Health and Safety	Expanding river oriented activities contribute to expanding exposure to river related risks.	Water quality improvements, spill prevention & response, improved monitoring has reduced river related risks.	Continued expansion of river oriented activities require improved water quality and monitoring to maintain low risk factors.	Control of contaminant sources affecting water contact recreation and fish consumption issues has slowed following early gains.
Cultural Resource s	Development threatens architectural and archaeological resources.	Regulatory oversight contributes to protection, impact avoidance, and mitigative actions.	Interpretations at landscape scale expand complexity of cultural resource protection.	Cultural resource protection most effective when part of planning & design vs. reactive assessment.
Water Quality	Improved public health, recreational opportunity, aesthetic values with improved water quality.	See recreation, health and safety comments.	Appears likely present water quality will be maintained or improved.	Broad and expanding public recognition of water quality benefits and value.
Air Quality	Improved public health and	See recreation, health and safety	Appears likely present air quality	Broad and expanding public recognition of

VEC	SR & EJ Factors & Impacts	Past/Present Trends	Future Trends	Comments
	aesthetic values with improved air quality.	comments.	will be maintained or improved.	air quality benefits and value.
Biological Resources (aquatic, riparian, T&E).	Resource recoveries contribute to improved recreational opportunity, aesthetic values.	See recreation, health and safety comments.	Expanding navigation, commercial/residential and recreational uses of river will conflict with habitat needs.	Long term protection/ management of significant habitat areas required to maintain Bio Resources

11.9 RELEVANT ACTIONS AFFECTING SOCIOECONOMIC RESOURCES AND ENVIRONMENTAL JUSTICE

RFFAs were evaluated for SR and EJ issues utilizing the RFFA Matrix (see Exhibit A). The matrix evaluation process resulted in identification of 15 RFFAs with high or medium high importance for SR issues and an additional 24 that were rated as having medium importance. Results of the RFFA evaluation for SR are summarized in Table 10 and discussed in further detail in text following the table. Results of the evaluation for EJ issues are summarized in Table 11-10.

TABLE 11-10
RFFA Cumulative Effects Matrix for Socioeconomic Resources VEC

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Impact	Importance
Navigation Investment Actions					
Lock Extensions/New Locks/Replacement or Rehabilitation	A	H	SL	+	M/H
L&D operation and maintenance	A	H	SL	+	L/M
Non-structural navigation improvements	A	H	E	+	L/M
Other Corps Actions					
Channel dredging/dredged material disposal	A	H	E	+	L/M
Navigation aids - Construction and O&M	A	H	E	+	L/M
Flood damage reduction projects					
levees/floodwalls	A	L	SL	+/-	M
channel modifications	A	H	SL	+	L/M
nonstructural measures (relocation)	A	H	SL	+	L/M
Emergency streambank stabilization (Sec. 14)	A	H	SL	+	L/M
Modification of Corps structures for env. improvements (Sec. 1135)	A	M	SL	+	L/M
Environmental restoration of aquatic ecosystems (Sec. 206)	A	M	SL	+	L/M
Recreation facilities – Cons. and O&M	A	H	SL	+	M

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Impact	Importance
ERP Projects - 5 categories	A	M?	SL	+	M/H
Port development (Sec. 107) and maintenance dredging	A	H	SL	+/-	M/H
Pool Maintenance	A	H	SL	-	M
"But for" Actions					
Commercial Navigation					
barge queueing	A	H	SL	-	M
fleeting areas/barge storage	A	H	SL	-	M/H
terminals	A	H	SL	+/-	M/H
multi-modal sites	A	H	SL	+/-	M/H
increased traffic	A	H	E	-	L/M
dispersed barge traffic	A	H	E	-	M/H
accidents/spills	A	H	E	-	M
USCG Navigation Aids	A	H	E	+	L/M
Instream sand and gravel mining	A	H	SL	+/-	M
Floodplain sand and gravel mining	A	H	SL	+/-	M
Limestone aggregates mining	A	H	SL	+/-	M
Coal utilities	A	H	SL	+/-	H
Other coal industries	A	M/L?	SL	+/-	M
Industrial users, excluding coal-related	A	H	SL	+/-	M
Recreation facilities – Cons. and O&M	A	H	SL	+	M
Actions by Others					
Park development and operations	A	H	SL	+	L/M
Floodplain development					
commercial	A	M	SL	+/-	M
industrial	A	H	SL	+/-	M/H
Crossings					
bridges	A	H	SL	+/-	M/H
Marina development & operation	A	H	SL	+/-	M/H
Water -based recreation					
boating	A	H	E	+	H
fishing	A	H	E	+	H
personal watercraft	A	H	E	+/-	M
wildlife watching	A	H	E	+	M
sight-seeing	A	H	E	+	M
Agriculture	A	H	R	+	M

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Impact	Importance
Waste Water Treatment Plant discharges					
municipal	A	H	U	+/-	M
industrial	A	H	U	+/-	M
Stormwater discharges	A	H	U	-	M
Brownfields redevelopment	A	H	U	+	L/M
Hazardous waste sites	A	H	SL,U	-	L/M
Natural Climatic Events					
floods	A	H	E	-	H
droughts	A	H	E	-	M
severe storms	A	H	E	-	M
Regulatory Environment					
Phase I & 2 NPDES program	A	H	SL, U	+	M
Site remediation	A	H	SL	+	L/M
More stringent quality standards for environmental media	A	H	E	+	L/M
Wetland Mitigation Banking	A	H	SL	+	L/M
Farmland preservation	A	H	SL, R	+	L/M
Emissions trading	A	H	SL	+	L/M
COE permitting programs	A	H	E	+	M/H
ORSANCO monitoring program	A	H	E	+	M
Spill response	A	H	E	+	M
Environmental sustainability practices	2,3	M	E	+	L/M

[1] Reasonably Foreseeable Future Actions
[2] Time period in which the RFFA may occur
1 = within 10 years, 2 = 10 - 25 years, 3 = 25 - 60 years, A = all time periods
[3] Occurrence probability or likelihood RFFA will happen
H = high M = medium L= low
[4] Location or setting on river where RFFA is expected to occur
U = upper (Pittsburgh - Huntington), M = middle (below Huntington - Louisville)
L = lower (below Louisville - mouth), E = along entire length of river
SL = specific location, e.g., locks and dams, U = urban setting, R = rural setting

11.9.1 Navigation Investment Actions

Lock extension, replacement or rehabilitation (Impact, +; Importance, M/H): Lock extension, replacement, or rehabilitation would result in creation of temporary employment for construction workers, but not creation of permanent jobs. Temporary employment of local unemployed or underemployed construction workers would be a benefit. Short-term local income and revenues would increase as a result of project related employment. No long-term changes to population, property values, local taxes, or existing land use patterns are predicted. Need for additional housing, utilities, or social services also are not

anticipated. On-site or near-by recreational uses may be closed or curtailed during construction.

Long-term positive impacts to efficiency of the navigation industry and reduced shipping costs are the principal justification for navigation improvements. However, future growth of navigation traffic is expected under all scenarios primarily due to continued economic growth.

11.9.2 Other Corps Actions

Port development and maintenance dredging (+/-, M/H): Potentially significant SR impacts include temporary employment increases during construction with associated increased local revenues. The possible development of new terminals and associated facilities would contribute to creation of new permanent employment and changes in property values and tax base. Recreational use would be restricted during construction, and could potentially be permanently altered with a consequent loss of associated revenues.

Ecosystem restoration projects (+, M/H): Short-term local income and revenues would increase as a result of project related employment and other expenditures. Completed projects would potentially enhance fishing and other recreational opportunities, with associated increased revenues. Long term protection of aquatic/terrestrial habitats is critical to protecting the economic viability of recreation oriented businesses.

Levees/floodwalls (+/-, M): These projects protect people and infrastructure investments and reduce or eliminate potential damage costs in flood prone areas. They also remove riparian land from floodplain functionality. These actions are rated 'medium importance' because little additional expansion of levees or floodwalls is expected for the Ohio River mainstem. However, the presence of levee/floodwall protection may contribute to redevelopment initiatives in depressed or underutilized portions of riverfront communities.

Recreation facilities, construction (by Corps or others), and O&M (+, M): These actions would expand the local economy by providing additional services, concessions, and limited new employment. Public access and opportunities to benefit from the resource would be enhanced. The value of nearby communities or shopping/commercial developments may also be enhanced.

Pool Maintenance (-, M): Landowner perceptions of riverbank property damages are attributed to pool elevation maintenance, other Corps actions, and perceived failure to regulate barge activity. State agency perceptions of damages to parks and wildlife management areas are also attributed to pool maintenance. Note the frequency of public comments (**see Table 11-1**) addressing this topic.

11.9.3 But for Actions

Coal Utilities (+/-, H): Coal fired power plants provide employment opportunities and potential development or expansion of related shipping facilities. Potential negative impacts are related to traffic and spills during transfer of materials. New utilities and

expansion of existing facilities will compete with other uses in limited floodplain areas and would result in losses of agricultural lands or riparian habitats. Coal utilities account for 60+ % of commercial traffic on the river and are expected to account for the majority of projected traffic growth.

Fleeting areas, barge storage (-, M/H): Fleeting activities can deter recreational use with loss of associated revenues to the local economy. Potential accidents and spills from fleeting activity adds increased costs. Locating fleeting areas away from shore helps reduce negative impacts but can be problematic during low flows with narrowed river widths. Fleeting activities are an unavoidable 'externality' of barge navigation that has resulted in conflicts with boaters, shoreline residents, and others. Controls and conflict resolution are likely to become more necessary as traffic growth results in continued expansion of areas used for fleeting.

Dispersed barge traffic (-, M/H): Negative economic impacts are associated with the increase in potential accidents and spills when barges fail to stay in designated shipping lanes. These impacts may discourage boaters, reducing associated recreation revenues. Bank tie-offs, groundings, and related shoreline encroachments result in bank erosion, property damage, and conflicts with shoreline residents. Note the frequency of public comments from scoping meetings (**see Table 10-1**) addressing these topics.

Terminals/multi-modal facilities (+/-, M/H): These facilities provide employment opportunities and potential development/expansion of related shipping facilities. Potential negative costs are related to traffic and spills during transfer of materials. New terminals and expansion of existing facilities will compete with other uses in floodplains and would contribute to losses of agricultural lands or riparian habitats.

Barge queuing (-, M): Idling of tows increases operation and shipping costs and potentially increases user conflicts (e.g., accidents) and associated costs. Shoreline stabilization costs may be incurred.

Accidents/spills (-, M): Short to long-term economic impacts vary with the extent of each spill. Resulting shoreline damages may incur costs for clean-up and possible litigation. Provisions for monitoring, spill detection/notification, and response systems help avert damage and associated economic impacts.

Mining activities – instream, floodplain (+/-, M): Mining in close proximity to the river benefits from availability of the navigation system. Impacts include local economic benefits, losses of instream and riparian habitats/functions, and the potential for restoration of riparian sites for recreation and/or habitat functions after completion of mining activity.

Other coal industries, other industrial activities (+/-, M): The navigation system and/or availability of water encourage the location of activities near the river. Impacts include local economic benefits and the loss of instream and riparian habitats/functions.

11.9.4 Actions by Others

Floodplain industrial development (+/-, M/H), floodplain commercial development (+/-, M): Further industrial or commercial development would generally create

employment opportunities, add to local revenues, and potentially change property values and the tax base. Concomitantly, public services would need to be extended with associated costs. Such facilities may or may not generate new business for the shipping industry. Development would take land from agricultural or riparian habitat uses.

New bridge construction (+/-, M/H): Short-term local income and revenues would increase as a result of project related employment and related expenditures. Significant changes to population, property values, local taxes, and existing land use patterns would likely occur (e.g., at a new interstate bridge). Long-term positive impacts to the efficiency of highway transportation and reduced trucking costs are the principal justification for new bridge construction or expansion.

Marina development and operation (+/-, M/H): Development of new marinas would result in temporary employment increases during construction with associated increased local revenues. Marina operations would result in some permanent employment and changes in property values and tax base. Increased recreational activity would generate new revenues for the local economy. Development would result in loss of agricultural lands or riparian habitats, particularly embayment wetlands. There is potential for future growth in this sector if recreational interests continue to grow.

Recreational Boating and Fishing (+, H): Boating generates significant trip-related and boat-related revenues (Husak, 1999). Fishing generates significant trip-, boat-, and equipment-related revenues. Commercial navigation, floodplain industrial or commercial growth, and other competing uses may limit capacity for continued growth of recreational activity on the Ohio River.

Water based recreation – Personal Watercraft (PWCs), wildlife watching, sight-seeing (+, M): These activities generate trip-related revenues, including income for excursion cruises from some larger ports. They also generate equipment purchase revenues. Potential social conflicts could occur if development activities threaten wildlife resources. Potential conflicts exist between incompatible activities such as PWC operation and wildlife watching. There is potential future growth of these activities if recreational interests continue to grow.

Agriculture (+/-, M): Agriculture provides jobs and income, along with food and fiber, and impacts vary with the size or type of operation. Implementation of proper BMPs can limit erosion, pollution, and other costly negative environmental impacts. Agriculture provides the foundation for rural community networks. Most future developments in floodplains would occur on agricultural lands.

Waste Water Treatment Plant (WWTP) discharges – municipal, industrial (+/- M): Clean industries and communities associated with properly functioning treatment systems can encourage economic growth. Pollution and aesthetic problems associated with malfunctioning systems can deter further development. Applies to collection systems (CSOs, SSOs, and infiltration) as well as to plants and discharges.

Stormwater discharges (-, M): Storm runoff from CSOs, SSOs and nonpoint urban surfaces contributes to bacteriological contamination and associated health risks. Significant investments are required to reduce or eliminate CSO and SSO discharges.

Implementation of proper BMPs can limit erosion, pollution, and other negative environmental impacts from storm runoff.

11.9.5 Natural Climatic Events

Flood Events (-, H): Flooding increases the potential for river-related accidents, including vessel casualties, barge breakaways, and pollution incidents along with associated adverse economic impacts. Enormous economic costs can occur when homes, businesses, and industries in flood-prone areas are damaged.

Extreme weather – droughts, storms (-, M): Low water conditions can increase potential for river-related accidents, including vessel groundings, barge breakaways, exposed river hazards, and pollution incidents, along with associated adverse economic impacts. Lower water levels decrease dilution of pollutants entering the river and increase retention time, potentially lowering water quality.

Severe storms can cause high economic losses related to damage from hail, high winds, heavy debris, lightning, and ice formation. Although these occurrences cannot be prevented, better forecasting and enhanced boater education can increase preparation and alleviate or avoid some adverse socioeconomic impacts.

11.9.6 Regulatory Environment

Corps permitting programs (+, M/H): To the extent that these programs address components of the Clean Water Act, they reduce pollutant discharges to local waterways with associated economic benefits. These programs also have implications for several VECs, including aquatic resources, land use, and health and safety. Corps permitting plays a potentially significant role where social conflicts arise over competing uses of resources.

Phase I & II NPDES (+, M): These programs should decrease the amount of stormwater and pollutants entering the river and their associated economic impacts. Because these programs are somewhat complex and costly to implement, many municipalities are establishing stormwater utilities to help fund them.

Ohio River Valley Sanitation Commission (ORSANCO) Monitoring (+, M): ORSANCO's various ongoing monitoring programs provide environmental and human health information with associated SR benefits (e.g., see spill response below).

Spill Response (+, M): Emergency response measures currently in place by ORSANCO, Coast Guard, USACE, EPA and various state agencies help to reduce accidental spills and associated clean-up costs. Spill detection and notification systems along the river have become increasingly sophisticated in the last 20 years. Rapid response and effective containment/recovery also minimizes the severity of spills.

11.9.7 Relevant Actions Affecting Environmental Justice

From the systemwide perspective of a CE study, EJ issues may tend to be overlooked. For example, the collective benefits of affordable electricity stemming in part from development and maintenance of the Ohio River navigation system would accrue to

EJ populations as well as to the general population of the region. Similarly, air pollution impacts stemming from coal combustion effect everyone, EJ populations do not appear to be disproportionately impacted. However, the appearance of no disproportionate impact systemwide may mask important differences on a local or site specific basis. Residents of urban areas exposed to seasonal concentrations of ozone contamination could be more seriously affected than commuters who spend part of each day in less polluted areas outside of the city.

The review of RFFAs resulted in very few indications of disproportionate impacts to EJ populations. **Table 11-11** and the subsequent discussion of individual RFFAs are intended to illustrate some of the more obvious possibilities, as well as to underscore the need to perform adequate EJ scoping at the individual project level.

TABLE 11-11
RFFA Cumulative Effects Matrix for Environmental Justice Considerations

RFFA[1]	Time Period[2]	Occurrence Probability[3]	Location on River[4]	Impact	Importance
Navigation Investment Actions					
Lock Extensions/New Locks/Replacement or Rehabilitation	A	H	SL	+/-	L
Other Corps Actions					
Flood damage reduction projects					
levees/floodwalls	A	L	SL	+/-	L
nonstructural measures (relocation)	A	M	SL	+/-	L/M
Recreation facilities – Cons. and O&M	A	H	SL	+	M

11.9.7.1 Navigation Investment Actions

Lock extension, replacement, or rehabilitation (Impact, +/-; Importance, L): Except for a few lock and dam projects located in urban settings (i.e., EDM) it is unlikely that construction related impacts would differentially effect EJ populations. Overall socioeconomic impacts of lock extension, replacement, or rehabilitation projects would be about the same for EJ populations as they would be for the general population. Temporary employment of local unemployed or underemployed construction workers would be a potential benefit of more direct importance to EJ populations.

As with any proposed major project, it is important to evaluate site specific characteristics of the project area to identify any populations that may require special communication, planning and involvement efforts, or that may be differentially impacted by the project.

11.9.7.2 Other Corps Actions

Flood damage reduction projects - levees and floodwalls (+/-, L): The benefits of flood protection accrue to all that live or work in areas protected by levees or floodwalls.

Federal laws and policies require that flood damages avoided (benefits) must exceed project costs. Areas with concentrations of low property values often do not receive flood damage reductions as projects in these locations do not have a positive benefit/cost ratio. Therefore, some localized neighborhoods with low income populations are likely to be disproportionately affected.

Flood damage reduction projects – nonstructural measures (+/-, M): Relocation of populations out of a floodplain can sometimes fit better with community needs than building flood control structures. This option can also be less environmentally damaging and offers opportunities for recreational and open space amenities in the floodplain (Johnson Creek, 2003). EJ communities face similar problems with project justification as for structural flood damage reduction measures discussed above. In cases where EJ populations or communities live in a project area, special steps may be necessary to avoid negative impacts to relocated individuals. If residences in the area were mostly rented, compensation may go primarily to property owners, while those who are actually displaced could receive inadequate compensation. Special efforts, including collaborative planning efforts with the impacted communities, would be required to assure that relocated families and communities are not harmed by the project (FHWA East-West EIS, FHWA SC Rt. 72 EA).

Recreation facilities – construction and O&M (+, M): Research conducted by the Corps indicates that some recreation facilities may be disproportionately popular with EJ populations (Gramann, 1996; Dunn, 1999). Factors such as accessibility, available activities, facility design, affordability, and safety can strongly influence the choices of minority groups. This research also suggests that studying the distributions and needs of EJ populations along the Ohio River could facilitate design of new parks or redesign of existing recreation facilities so as to provide enhanced recreational opportunities for these populations. See Chapter 9, Recreation, for more discussion of planning and design of recreational facilities on the Ohio River.

11.10 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

One of the seven environmental operating principles of the Corps is to strive to achieve Environmental Sustainability (ES). ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation, and maintenance to improve the quality of life for present and future generations. Accordingly, ES represents an "ultimate test" whereby the significance of CE can be evaluated. This test is applicable for programmatic impact studies wherein a broad, "high altitude" perspective is utilized. An Analysis of Environmental Sustainability (AES) has been and is being used in several other programmatic studies by the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps:

(1) identification of "common effects" on SR parameters from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix;
(2) selection of sustainability indicators for SR, and their grouping, as appropriate; and

(3) consideration of the "connections" between the common effects and the indicator groups

The output of the AES consists of a qualitative (descriptive) discussion of the "connections", with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions – what is the current ES for SR, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable – composite conditions for the selected indicators of ES for SR do not reflect conditions that would facilitate attainment of acceptable standards or would not maintain existing standards in concert with collective impacts of proposed activities.

- Marginally sustainable – composite conditions for selected indicators of ES are such that attainment of acceptable living conditions and quality of life is accomplished for the majority, but not all, of the potentially affected populations. However, the conditions of indicators are somewhat tenuous both in location and likelihood of occurrences (in other words, the conditions are "borderline" for ES, and there are uncertainties regarding specific quantitative measures for the ES of SR for the Ohio River).

- Sustainable – composite conditions for selected indicators of ES are such that attainment of acceptable living conditions and quality of life is accomplished for essentially all of the potentially affected populations in the Ohio River Valley, and such standards are maintained in concert with foreseeable future activity. Further, conditions of the indicators exceed regulatory thresholds, and various governmental programs are in place to respond to any potential erosion of SR values.

Common effects of multiple actions have been previously discussed in the sections entitled "Interactions with Other VECs" and "Relevant Actions Affecting SR".

Indicators or groups of indicators of ES were identified earlier in the section entitled "Indicators of Sustainability", and relevant information on them have been presented in the section entitled "Past to Current Baseline Conditions". For purposes of this analysis, the above indicators are grouped into three tiers for the AES. The three tiers are as follows:

- first tier – "scientific measures of socioeconomic resource factors"
  (1) Census counts of population, including minority and economically disadvantaged populations.

  (2) Census counts of income, educational attainment, health status, household composition, and other indicators of socioeconomic status.

- second tier – "composite measures of socioeconomic resource factors"

(1) Census and Bureau of Economic Analysis calculations of households in poverty, per capita income, employment levels by SIC code, and unemployment rates.

- third tier – "composite indicators of SR sustainability;" this includes measures developed from multiple indicators

(1) Projections based on fertility, mortality, immigration, labor force participation, and growth of national productivity.

Finally, the indicators and tiers are displayed in **Table 11-12**. The first column in **Table 11-12** divides the RFFAs into three broad groups. The first group includes actions that sustain the broad spectrum of socioeconomic viability throughout the Ohio Valley region. The Ohio River navigation system is included as one of the important infrastructure components of the region. The combined effects of these 'major factors' are most directly linked to the socioeconomic measures and indicators summarized in the latter columns. The second group in column one includes actions that are necessary to the long-term maintenance of the navigation system, such as infrastructure maintenance and dredging of the navigation channel. Potential modifications of present day lock systems are included in this group. Finally, the third group looks at the negative SR effects of those actions that are necessary to maintenance of the navigation system.

When comparing actions that may impact sustainability of SR, the most appropriate composite measures and indicators are those that reflect the general health and well being of people affected by such actions. The primary indicator of SR sustainability used in this chapter is the baseline county-level projection of populations for Ohio River states prepared by the economic consulting firm NPA Data Services (NPA, 1999). NPA's key forecasting assumptions involve several demographic and economic variables. The demographic variables are fertility, mortality, and immigration rates. The economic variables are labor force participation and the growth of national productivity, or product (GDP) per worker. Projections of stable to slowly expanding populations are interpreted within the context of these measurements as the most desirable outcomes. Declining populations are interpreted as an indicator of undesirable SR conditions and rapidly expanding populations are interpreted as an indicator of significant changes in the community that may produce a mix of desirable and undesirable outcomes.

On a more localized basis such as a project specific assessment, socioeconomic analysis as outlined above should be supplemented with more specific indicators of general health and well being. This can be largely accomplished by following the guidelines for assessing EJ issues presented earlier in this chapter (see 11.6.1 Legal Mandates and 11.6.2 Agency Guidelines). Potential indicators at the community level could include income related to local cost of living, infant mortality rates, average life expectancy, home ownership rates, and crime rates. Selection of appropriate indicators and SR study design at the community level needs to be based on characteristics of the local community and the nature of the proposed action.

11.11 Conclusions

The general socioeconomic projection for the Ohio River Valley is 'sustainable' for the present and into the foreseeable future. The region offers a reasonably healthy mix of agriculture, varied industries, and commercial, financial, education, and health care services and is supported by a fully developed economic infrastructure. This economic infrastructure includes rail, highway, river, and air transportation, modern communication capabilities, and affordable and reliable utilities, including coal fired electricity generation that depends directly on the river navigation system. The social system is equally well established, with a generally healthy, educated and technically skilled population supported by an established network of urban, suburban and rural communities.

The projected slow population growth and attendant slow growth of the economy allows for a gradual expansion from the existing infrastructure and an opportunity for relative economic stability in contrast to the 'boom and bust' patterns of the past century. Instead of the past pattern of rapid conversion of resources and landscape to meet the industry and infrastructure demands of a rapidly expanding population, there is an opportunity to proceed with a gradual and better planned process of development and redevelopment serving the needs and interests of a stable and established population. This steady pattern for development should score higher for sustainability than the more volatile pattern of explosive growth and recession cycles.

Ongoing investments in social and economic infrastructure should have a generally positive impact on SR values. For the Ohio River Valley, most primary infrastructure investments have already been accomplished. This includes a complete system of interstate and other primary highway networks, railroads, river bridges, airports, locks and dams, levees, and floodwalls. Expansion plans for much of this system continue on the basis of projected demand or existing capacity expansion needs, but a relatively stable population for the foreseeable future should contribute to reduced demand for additional primary infrastructure. Future improvements to this system would focus primarily on maintenance, refinement, or replacement of existing inventory.

Improved water quality has contributed to increased redevelopment interest for many riverfront neighborhoods. Growing interest in environmental amenities within residential/commercial settings contributes to the design of community oriented restoration projects that combine floodplain functionality, aquatic and riparian habitat enhancement, open space, recreational activities, stormwater detention, and related functions within multi-purpose or integrated aquatic restoration projects. Maximization of restoration opportunities may be realized by their inclusion within master-planning approaches to mixed-use community redevelopment.

Both lock extension/replacement and ongoing maintenance/repair of existing locks would contribute to positive SR impacts. Within the context of the larger economy of the Ohio River Valley, these actions would contribute fairly small, but cumulative impacts. Long term growth of navigation traffic will require more tugs and barges in operation, more terminals and related port facilities, more maintenance dredging for expanded

terminals, and expanded areas of fleeting operations. These expansions would convert existing floodplain lands (e.g., farmland, riparian woods, and wetlands) that now afford habitat protection, open space, and ecosystems values. Once converted, such lands are unlikely to revert to their former more natural states. Expansion of navigation infrastructure would also compete for space with expansion of riverfront industries, coal fired utilities, mining, and other commercial operations. Mixed-use urban waterfront developments, marinas, and other recreation-oriented developments would also compete for waterfront space. Waterfront development policies that support conversion of brownfields, unused or underdeveloped terminals, or other underutilized industrial sites could help minimize conversion impacts to existing agricultural uses or riparian habitats. **Figure 11-6** illustrates the historic through future trends for SR sustainability in the Ohio River study area.

Table 11-12 illustrates the relationship between applicable RFFAs and their effects on SR.

FIGURE 11-6
ES of Socioeconomic Resources

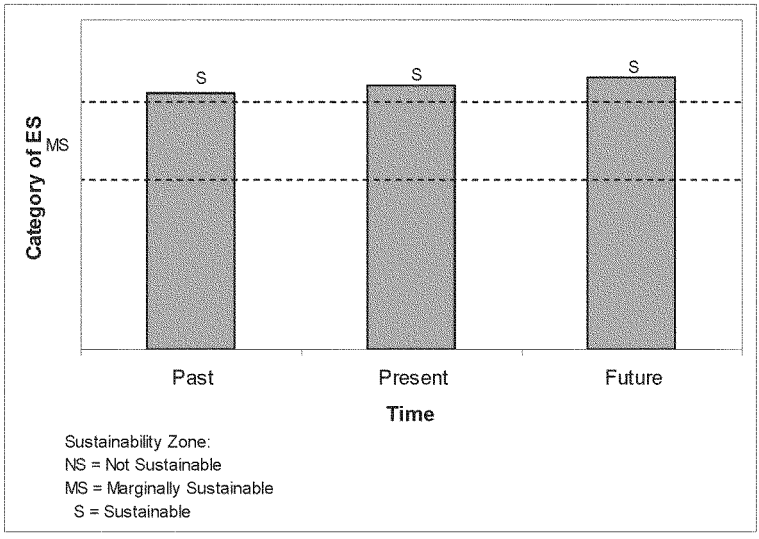


TABLE 11-12
AES Tiers for Actions Causing Socioeconomic Effects

Actions Impacting SR Sustainability	Scientific Measures Of Socioeconomic Resource Factors	Composite Measures of Socioeconomic Resource Factors	Composite Indicators of SR Sustainability
• Actions that sustain SR viability – navigation system, coal utilities, mining, other industry, levees/floodwalls, other (e.g., bridges). • Actions that sustain navigation system – lock extensions, pool maintenance, channel dredging. • Negative SR impacts of navigation system – pool maintenance, channel dredging, fleeting, dispersed barge traffic, barge queuing, accidents & spills.	• Census counts of population, including minority and economically disadvantaged populations. • Census counts of income, educational attainment, health status, household composition, and other indicators of socioeconomic status.	• Census and BEA calculations of households in poverty, per capita income, employment levels by SIC code, and unemployment rates.	• Projections based on fertility, mortality, immigration, labor force participation, and growth of national productivity.

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Chapter 12
CULTURAL RESOURCES

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References

12.2 DEFINITION OF RIVER-RELATED CULTURAL RESOURCES

Cultural Resources (CR) reflect past cultural, historic, and environmental influences. For the Ohio River Main Stem System Study (ORMSS), CR include, but are not limited to districts, sites, buildings, structures, landscapes, and objects in or eligible for the National Register of Historic Places (NR). Such resources are associated with or representative of peoples, cultures, human activities, or events, either in the past or present, and include related artifacts, records, and material remains. Among the types of CR considered are:

- Prehistoric CR such as the remains of Native American villages, campsites, rockshelters, and petroglyphs;
- Historic resources such as farmsteads, mills, covered bridges, and foundations of early historic structures;
- Industrial resources such as railroad bridges and tunnels, factories, kilns, and the early river locks and dams;
- Historic landscapes such as parks, gardens, farms, quarries, etc.; and

- Districts where significant numbers of CR are grouped together.

Further, the U. S. Army Corps of Engineers (USACE), in its current Planning Guidance Notebook (PGN), published April 22, 2000, includes the following definition:

An historic property is any prehistoric or historic district, site, building, structure, or object included in or eligible for inclusion on the National Register of Historic Places (NRHP). Such properties may be significant for their historic, architectural, engineering, archeological, scientific, or other cultural values, and may be of national, regional, state, or local significance. The term includes artifacts, records, and other material remains related to such a property or resource. It may also include sites, locations, or areas valued by Native Americans because of their association with traditional religious or ceremonial beliefs or activities.

CR are identified among the Valued Environmental Components (VECs) in this CEA not only because they are part of the environment, but also because they reflect events and cultural values that were shaped by the response of humankind to the environment. Much of what is significant about a particular cultural resource is related to climatic conditions, natural setting, and locally available building materials.

Finally, while CR are generally associated with or representative of peoples, cultures, human activities, and events in the past, they are not immune to change and are in a sense evolving. Under the NRHP age criteria, any resource over fifty (50) years of age must be considered for potential inclusion in the NRHP (less than fifty years must be exceptionally significant). In fact, some CR being developed or constructed today may actually gain eligibility for listing on the NRHP within the ORMSS time frame, which extends through the year 2070.

12.3 OBJECTIVES AND SCOPE OF THE CULTURAL RESOURCES STUDY

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of Reasonably Foreseeable Future Actions (RFFAs) by the Corps and others. This chapter assesses the system-wide cumulative effects (CE) on CR of all likely major navigation improvements and other developments and trends along the main stem of the Ohio River from 2000 to 2070. Impacts directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present, and future actions. Future actions include the major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, actions by non-governmental entities, and predictions of general economic expansion and development, as well as regulatory changes.

The results of the Cumulative Effects Assessment (CEA) will lead to further consideration of:

1) acceptability of impacts of the RFFAs on affected CR
2) how proposed navigation improvements contribute to those impacts and
3) what constitutes a sustainable system for CR of the main stem Ohio River.

12.3.1 Geographic Scope

The geographic focus for CR impacts includes those regions most directly impacted by operation and maintenance of the navigation system. This focus encompasses CR located in the river itself and on lands along either bank of the Ohio River lying "between the bluffs." This "floodplain zone" is defined as the meander channel of the Ohio River and includes the 100 and 500-year floodplains as well as terraces of level land lying above these flood zones. Because of their proximity to the Ohio River as a reliable water source, these floodplains and their associated terraces have long been recognized as potentially important areas for CR.

12.3.2 Time Frame

The established time frame for the assessment of most VECs is 1920 to 2070. The earlier date approximates initiation of modern Corps lock and dam construction activities on the Ohio River. The latter date approximates the end of the 60-year planning horizon encompassed by the ORMSS. The CR discussed in this chapter, however, are not confined to the project time frame, but encompass both prehistoric and historic times.

12.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during the Summer of 2001 in communities along the Ohio River. The meetings created opportunities for the public, state, local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. A more detailed discussion of the scoping meetings is presented in Exhibits A and B of this report. The meetings were attended by 185 persons, and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted. Comments that directly and indirectly addressed CR are presented in **Table 12-1** below.

TABLE 12-1
Comments from Public Scoping Meetings

Direct Comments on Cultural Resources	Relevance to Cultural Resources	Total Comments
Need to address the Native American Grave Protection and Repatriation Act (NAGPRA)	Conformance of USACE action to this law	3
Need to contact State Historic Preservation Offices (SHPOs) when specific projects are proposed	Importance of notifying appropriate state agencies	1
Eligibility of locks for classification as historic structures	Appropriateness of designating locks as cultural resources	1
Other Comments with Implications for Cultural Resources	**Relevance to Cultural Resources**	
Potential adverse effects of higher pool elevations on bridges, other infrastructure and property	Potential loss or damage to cultural resources	6
Need to develop comprehensive plans for development along river	Potential loss or damage to cultural resources	3
Will USACE do site-specific documents for each action?	Potential loss or damage to cultural resources at specific sites	1

12.5 INDICATORS OF ENVIRONMENTAL SUSTAINABILITY

While indicators of ES, which vary by VEC, generally provide benchmarks for measuring cumulative effects on a given resource or VEC, most CR are unique and nonrenewable, because they were created or occurred at specific geographic locations at certain points in time by different individuals or groups. Often the circumstances that created each resource, consequently, are unique and cannot be duplicated. Bearing these circumstances in mind, indicators of sustainability for CR include:

- Number of properties/sites within the study area listed or eligible for listing in the National Register of Historic Places or listed in any special state listings;
- Physical condition of properties/sites within the study area listed or eligible for listing in the National Register of Historic Places or in any special state listings;
- Integrity/stability of the context of important CR, including factors indicative of carrying capacity (including auditory, visual, atmospheric encroachment, and overuse), if public access is provided;
- Site frequency/importance of a site (or collective grouping of certain sites) within the study area and at the state and national levels;
- Effectiveness of Federal regulations and SHPOs in preserving CR within the study area; and
- Level of efforts necessary to minimize impacts or recover artifacts and information from unavoidable past and future actions.

Because all materials deteriorate naturally over time, CR are not inherently sustainable. The indicators of sustainability presented above, therefore, represent efforts to prevent or slow natural deterioration. Carrying capacity of CR, as manifested by their

condition, must be closely monitored if the resources are to be sustained. Allowing public access to a cultural resource, for example, exposes that property to increased risk of deterioration or destruction. Furthermore, precautions must be taken to ensure that providing access to CR does not inadvertently contribute to the environmental deterioration of other VECs.

Preservation of representative CR throughout the full prehistoric to historic timeline is desirable. To achieve this goal, information on the frequency or importance of a cultural resource within the study area helps in allocation of energy and economic resources channeled toward preservation efforts, especially when fiscal resources are limited.

12.6 LAWS, REGULATIONS, ORDINANCES, AND PROGRAMS

Several regulatory actions influence CR in the study area. **Table 12-2** presents information on important laws, regulations, or established programs that influence CR in the Ohio River Valley.

TABLE 12-2
Institutional Actions Relevant to Cultural Resources

Law/Program (Lead Agency)	Key Components	Relevance to Cultural Resources
Archaeological Resources Protection Act 1979 (ARPA) (US Dept. of the Interior)	Protects cultural resources on federal and Indian lands.	Prohibits the removal, excavation, or alteration of any resource from federal or Indian lands except by permit issued from the DOI.
Historic Sites, Buildings and Antiquities Act 1935 (HSA) (National Park Service)	Established a national policy to preserve historic sites, buildings, and objects of national significance for the inspiration and benefit of the people of the U.S. The Act also authorizes and directs the Secretary of the Interior to make a survey of historic and archeological sites, buildings, and objects for the purpose of determining which possess exceptional value in commemorating or illustrating the history of the US	Created the National Historic Landmark (NHL) Program within the NPS. NHLs are designated unilaterally by the SOI, based on recommendations by an advisory council. NHLs are automatically listed in the NRHP. The SOI will consult with federal agencies and others before making an NHL designation.
Archaeological and Historic Preservation Act 1974 (AHPA) (US Dept. of the Interior)	Extends protection to scientific, prehistoric, and archaeological data from all federal undertakings and requires the federal agency to notify the DOI about adverse impacts.	Specifically provides for the preservation of historical and archeological data (including relics and specimens) which might otherwise be irreparably lost or destroyed.

Law/Program (Lead Agency)	Key Components	Relevance to Cultural Resources
National Historic Preservation Act of 1966 (NHPA) (Federal agency varies by project)	Established the primary policy; sections 106, 110, and 111; and authority for preservation activities.	Provided funding for the establishment of state preservation offices, restoration projects, surveys, and staff.
Native American Graves Protection and Repatriation Act (NAGPRA) (National Park Service)	Gives ownership of Native American cultural items- human remains, funerary objects, sacred objects, and items of cultural patrimony- to lineal descendants of the deceased, tribes on whose lands the items are recovered from, or to culturally affiliated tribes.	Requires on federal or tribal lands any intentional excavation of Native American burials and other cultural items or inadvertent discoveries of such items be carried out according to specific provisions and in consultation with the appropriate tribe.
Abandoned Shipwreck Act (ASA) (National Park Service)	Establishes US title to all abandoned shipwrecks on submerged State lands that are either embedded in such lands or included in or determined eligible to the NRHP.	Guidelines are intended to maximize the enhancement of cultural resources. State and Federal agencies are free to adopt the Guidelines in their entirety, make changes to accommodate the diverse needs of each State or agency, reject parts as inapplicable, or use alternative approaches. Creation of public underwater parks and preserves is encouraged, and investigations of historic shipwrecks which remain in federal jurisdiction require federal ARPA permits.
National Environmental Policy Act (NEPA) (Council on Environmental Quality and other agencies)	Requires preparation of an environmental impact statement for every major federal action affecting the human environment, which is defined to include cultural resources.	An EIS must include the comments of the Advisory Council on Historic Preservation for cultural resources identified for the project.
Corps' Permitting Statutes (U.S. Army Corps of Engineers)	Section 10 of Rivers and Harbors Act (1899) prohibits the unauthorized obstruction or alteration of any navigable water of the United States. Section 404 of CWA authorizes the Corps to issue permits for the discharge of dredged and fill materials into waters of the U.S..	Corps' permit analysis and resultant decision document must address cultural resources and any comments from SHPOS and/or the ACHP.

Law/Program (Lead Agency)	Key Components	Relevance to Cultural Resources
Executive Order 13287 "Preserve America"	This EO restates and emphasizes the policy originally established in the NHPA that calls for the federal agencies to take a leadership role in preserving America's heritage.	Seeks federal agencies to maximize integration of the NHPA into their programs, by using partnerships with state, local, and tribal governments and the private sector to promote preservation consistent with agency missions, and designating a senior policy level official to oversee the agencies historic preservation program, and promote the re-use of historic properties for heritage tourism and appropriate related economic development related to historic and natural sites on federal lands
State cultural resources regulations (PA Bur. For Historic Preservation, WV & OH State Historic Preservation Offices, KY Heritage Council, IN Div. Of Historic Preservation & Archaeology & IL Historic Preservation Agency)	Various regulations and programs administered by each state historic preservation office (SHPO). Includes excavation/survey permit requirements, documentation standards, penalties for disturbance or damage to cultural resources, criteria for historic designation, easements, etc.	Provides state-specific protection and preservation of cultural resources.

In 2004, a programmatic agreement was drafted between the Pittsburgh, Huntington, and Louisville Districts of the Corps, the National Advisory Council on Historic Preservation (ACHP) and the State Historic Preservation Officers (SHPO) of states bordering the Ohio River. This agreement was developed to ensure that projects related to modernization of the Ohio River navigation system shall be administered in accordance with the Corps' responsibility under Section 106 of the National Historic Preservation Act (NHPA).

12.7 PAST TO CURRENT BASELINE CONDITIONS

CR along the Ohio River are rich and varied, reflecting human occupation and significant events in the Ohio River Valley over many centuries. Both the prehistoric and historic CR of the Ohio River point to the central role of the river as a transportation artery in sustaining permanent settlements. In both prehistoric and historic times, human settlements developed along the Ohio River and its tributaries because its floodplains offered rich soils and the river offered food, water, and opportunities for trade. Later, the Ohio River and its tributaries were used in relation to early industries, river transportation, and trade routes.

12.7.1 Prehistoric Cultural Resources

The prehistoric periods of human occupation of the Ohio Valley are listed in **Table 12-3**.

TABLE 12-3
Prehistoric Periods in the Ohio Valley.

Period	Dates
Paleoindian/ Dalton	12000 – 8000 BC
Archaic	8000 – 1000 BC
Early	8000 – 6000 BC
Middle	6000 – 4000 BC
Late	4000 – 1000 BC
Woodland	1000 BC – AD 1000
Early	1000 – 300 BC
Middle	300 BC – AD 400
Late	AD 400 – 1000
Late Prehistoric	AD 1000 – 1600
Contact	Post AD 1600 (some overlap with Late Prehistoric)

The following prehistoric overview borrows heavily from Purtill et al. (2001), Weed (2004), Snyder et al. (2002), and Snyder and Anderson (2002).

The Paleoindians were the earliest inhabitants of the New World that archaeological research has been able to document unequivocally. These people entered the New World during the Wisconsinan glaciation and occupied a Midwest that was environmentally very different from current conditions. The climate was colder than at present, and much of the region was covered by a mosaic of tundra, grasslands, coniferous forests, and deciduous forests. Large mammals that are now extinct or confined to more northern regions of the continent, such as mammoths, mastodons, musk-oxen, giant moose, giant beaver, and caribou, ranged over much of the eastern United States (Brown and Cleland 1968).

The Paleoindian period is well documented in the western United States, where numerous archaeological sites have yielded distinctive Paleoindian fluted points in association with extinct Pleistocene mammals. The Paleoindian tool kit also includes end scrapers, side scrapers, gravers, drills, and large blades (Griffin 1967; Witthoft 1952). Largely by analogy with the Great Plains data, Midwestern Paleoindians are thought to have been specialized big game hunters who were organized into small, mobile bands that ranged over extensive territories (Ford 1974, 1977), but few sites have been identified that are sufficiently intact to permit testing these ideas (Chapman 1975). Data recovered at Kimmswick, Missouri (Graham et al. 1981), however, indicate a varied subsistence base for the Clovis culture, with the faunal remains from this site ranging from squirrels to mastodons.

In the Midwest, Paleoindian sites are usually recognized by the presence of fluted projectile point forms, such as the Clovis point, the Cumberland point, and, less

commonly, the Folsom point. Lanceolate forms such as Beaver Lake, Quad, and Agate Basin appear later in the period. While there is overlap of these point types Folsom tends to be a type found west of the Mississippi River while Cumberland points are found east of the Mississippi River. Clovis points have been recorded both from the west coast to the east coast. Recent research by Anderson and Faught (1998) for the contiguous United States has shown that 73.9 percent of fairly reliable provenienced Paleoindian points are located east of the Mississippi River while 26.1 percent are located west of the Mississippi River with points from Minnesota placed in the latter group. This research has also shown that distribution of fluted points across the lower 48 states is not continuous but clusters around major river catchments east of the Mississippi River, on either side of the Appalachian Mountains, the Southern Plains, and in central and southern California.

Evidence for Paleoindian occupation of the Ohio River Valley is meager. The only major Paleoindian site identified in the region is Meadowcroft Rockshelter in the upper Ohio River Valley in southwestern Pennsylvania. Radiocarbon dates from the site suggest an earlier occupation of the region than is generally accepted (Carlisle and Advasio 1982). Winters (1967) mapped distribution of approximately 100 fluted point finds in the Wabash Valley of the lower Ohio River Valley and discovered that they were almost equally divided between the uplands and the river terraces. The largest and most diversified Paleoindian sites in southern Indiana are found on terraces along the Ohio River and its major tributaries with a high concentration of sites also occurring in the "chert belt" region of Indiana where high quality Wyandotte chert was exploited (Cantin 1994). The Alton Site is located in eastern Perry County, Indiana, near the Ohio River and has been collected by amateur archaeologists. Curtis Tomak conducted test excavations at the site in 1984 (Tomak 1994). Two sub-plow zone features were identified but could not be definitely related to the Paleoindian occupation of the site. A single Clovis point in a private collection can be attributed to the site. However, most of the diagnostic projectile points/knives are Late Paleoindian types including Plano, Agate Basin, Beaver Lake, and Quad. These point styles suggest dates for the site in the range of 8,500 to 8,000 B.C. (Sieber et al. 1989).

Large Paleoindian sites found near floodplain ponds in Indiana suggests that floodplain and possibly aquatic/semiaquatic resources were being exploited along with the big game mammals (Higgenbotham 1983). Cultural material from the Paleoindian period has not been identified during recent cultural resource surveys in the western Shawnee Hills of Illinois. It is possible, however, that buried components dating to this cultural period may occur on high terraces within the major drainages of the region, or within some of the many rockshelters present in the uplands. In Ohio, several factors appear to influence the location of Paleoindian sites: (1) fluted points frequently are found in major stream valleys and confluences; (2) they tend to occur in proximity to quality flint resources; and (3) these points are rarely found in extensive swampy lowlands or in rugged highlands such as the unglaciated portions of southeastern Ohio (Purtill et al. 2001; Seeman and Prufer 1982). Gardner (1979) defined six Paleoindian site types: isolated finds; quarry sites; quarry reduction sites; base camps; base camp maintenance stations; and outlying hunting sites.

Paleoindians likely subsisted on a balanced hunting economy with the additional exploitation of wild plants. As the post-glacial climate and, in turn, the environment changed, humans were forced to adopt new subsistence strategies.

The Dalton period is recognized as a distinct transitional period between the Paleoindian and Archaic periods and appears to represent an adaptation to a warmer, post-glacial climate (Chapman 1975; Morse and Morse 1983; Wright 1987). Goodyear (1982) suggests a date range of approximately 8500 B.C. to 7900 B.C. for the Dalton period. Dalton type projectile points are commonly found in the lower Ohio River Valley in Illinois, Indiana, Kentucky, and to a lesser extent in the upper Ohio River Valley in Ohio and West Virginia. Dalton represents the transition phase between Paleoindians and the following period in archaeological chronology, the Archaic (Muller and Davy 1977). The Dalton period is characterized by a specialized knife form referred to by archaeologists as "Dalton Serrated." These artifacts resemble fluted points in shape, but their deep, concave bases are unfluted. Like Paleoindian societies, Dalton social organization was characterized by small mobile bands, but all faunal remains that have been found at Dalton sites to date are modern species (Chapman 1975). The Dalton tool kit indicates that a wide range of animal and plant foods were exploited, including small mammals, deer, nuts, berries, and seeds (Chapman 1975; Wright 1987). The Dalton tool kit includes distinctive concave base points as well as a small, distinctive adze, snubbed-end flake scrapers, bone needles and awls, mortars, manos, and hammerstones. The subsistence pattern of the Dalton period appears to have been considerably broader than that of the preceding Paleoindian period.

The division between the Paleoindian/Dalton periods and the Early Archaic period (8000-6000 B.C.) is an arbitrary one. It has been argued that Early Archaic lifeways were relatively unchanged from earlier Paleoindian/Dalton times throughout the Ohio River Valley (e.g., Adovasio et al. 1998; Raber et al. 1998). The climatic warming following the retreat of the glaciers around 8000 B.C. continued into the Archaic period in the Midwest. Deciduous forests containing oaks, hickories, walnuts, and other plant species that produced edible fruits and nuts expanded northward over much of the Midwest. In response to these environmental changes, prehistoric societies gradually broadened their subsistence strategies. Plant foods, particularly nuts, became increasingly important in the human diet (Ford 1974, 1977). Population tended to increase, and Archaic bands became larger and more sedentary. These trends were only beginning during the Early Archaic period, but they became more evident by Middle and Late Archaic times (Ford 1977).

The Early Archaic period was a time of significant change in the subsistence strategies in the Midwest as climatic changes continued to develop new ecological niches that produced new and varied food sources. Plant gathering and the harvesting of aquatic resources augmented traditional hunting and foraging strategies as floodplain lakes, sloughs, and marshes developed. The Archaic pattern of seasonal resource scheduling starts in the Early Archaic (Weed 2004; Caldwell 1958). Projectile point styles changed from unnotched lanceolate forms to corner- and side-notched forms. These forms include the Thebes, Kirk Corner Notched, Kirk Stemmed, Kirk Serrated, Hardin, St. Charles, McCorkle, and Lake Erie/Kanawha points (Justice 1987; Sieber et al. 1989). However, the Kirk, LeCroy, and Thebes projectile point types, which are present in this general area, indicate the continued exploitation of larger animals over vast territories by presumably small hunting bands (Dragoo 1976). Also characteristic of some projectile forms is the beveling of opposite blade edges, a product of resharpening. This may suggest that these tools were serving several different functions. Scrapers, burins, and chipped stone blades suggest an expansion of the tool kit and perhaps changes in tool function from earlier periods. The addition of sandstone abraders and mortars to the Early Archaic tool kit suggests that vegetable foods were becoming a more substantial part of their diet.

Early Archaic projectile points are numerous in the Midwest occurring on all locations of the landscape. Isolated points are found in large numbers in the uplands along secondary drainages, springs, and sinkholes (Sieber et al. 1989). The extensive use of rockshelters and caves also occurs about this time (Goodyear 1982; Kelly and Todd 1988). The majority of Early Archaic sites in the Midwest have been found on low terraces in major stream valleys. In the upper Ohio River Valley the Meadowcroft Rockshelter (Carlisle and Adovasio 1982) and the Goddard site (Koetje 1998) produced Early Archaic features. Excavations at buried, stratified Early Archaic sites in the lower Ohio River Valley of Kentucky (Collins 1979), and the Swan's Landing site in Indiana (Smith 1986) suggest a subsistence strategy organized around short-term, seasonally occupied camps. Swan's Landing in Harrison County was an extraction camp where chert reduction and tool manufacture took place near exposures of Wyandotte chert. In southern Illinois, Early Archaic sites are much more common than Paleoindian and Dalton sites, but many are shallow and prone to disturbance. A number of Early Archaic projectile points have been collected during several recent surveys within the Shawnee Hills (Canouts et al. 1984; Moffat et al. 1985; Penny 1983; Pulcher et al. 1987). Early Archaic components were also recorded at the Rose Hotel in Hardin County, Illinois (Wagner and Butler 1999). It is likely that Early Archaic sites within the floodplain of the Ohio River Valley are buried by Holocene alluvium.

A single Early Archaic phase has been defined in southwestern Indiana. The Jerger phase was established based on excavations at the Jerger site in Daviess County (Tomak 1979). The Jerger site functioned as a mortuary complex and contained crematory basins and grave goods including red ocher, perforated teeth, bone artifacts, marine shells, bifacial chert objects, drills, and Jerger projectiles (Tomak 1986). Presence of marine shell suggests that some form of long distance exchange was established by this date.

The Middle Archaic period coincides generally with the Hypsithermal, a period of higher average temperatures and reduced precipitation that occurred during the Middle Holocene (Wendland 1978). During this period, the expansion of grasslands opened new ecological niches and human settlement and subsistence strategies adapted to these drier conditions. The arboreal composition of Midwestern forests was essentially modern by 6000 B.C.

The Middle Archaic has been characterized as continuing the trend toward a broad-spectrum pattern of subsistence and toward more efficient adaptation to forested environments (Caldwell 1958; Ford 1977). This trend is reflected by the diversification of tool kits and the appearance of more groundstone tools, including full-grooved axes (Griffin 1967). In many of the larger river valleys of the Midwest, Middle Archaic populations apparently became larger and more sedentary (Jefferies 1987). The Middle Archaic tool kit closely resembles that of the earlier period with the inclusion of ground stone tools. Projectile points of this period are characterized by side-notched forms such as the Faulkner/Raddatz, Godar, Karnak, and Matanzas. Sites throughout the Ohio River Valley show changes in projectile point styles and usage of a greater variety of lithic raw materials. Groundstone artifact types include pendants, bannerstones, nutting stones, pestles, and plummets. Bone and shell artifacts such as awls, antler projectile-points, antler atlatl-hooks, bone fish-hooks, engraved bone pins, tortoise-shell cups and rattles, mussel-shell pendants, and necklaces of mammal teeth also were commonly made during the Middle Archaic period. The presence of mortars, pestles, and manos on Middle

Archaic sites suggests an increased reliance on nuts and grains. Along with the ground stone tools used in the processing of food resources most diagnostic of the Middle Archaic period is the appearance of the atlatl weight (Ballweber 1990). Aquatic resources also increased in importance as indicated by bone fishing hooks, net sinkers, and extensive shell middens. Hunting small animals and collecting nuts and seeds appear to have been the focus of Middle Archaic food-gathering practices, but the emphasis given different resources appears to have varied depending on local environmental conditions. Large, year-round occupations have been documented in river valleys in some regions of the Midwest, but small, briefly occupied sites from other topographic and environmental zones are also known.

Evidence from across the Midwest suggests that populations during the Middle Archaic became concentrated along the major river valleys with the large expanses of upland prairie and forest being largely abandoned (C. Chapman 1975; Conrad 1981; Munson 1988; Sieber et al. 1989; Stafford et al. 1988). Munson (1988) and Stafford et al. (1988) have recognized a similar shift in settlement strategies in southwestern and southern Indiana with camp sites being relocated in the principal stream valleys with upland areas apparently being restricted to short hunting and gathering forays. This shift in settlement appears to be an adaptive response to environmental change. In the uplands, conditions became warm and dry while in the major river valleys slack water lakes, ponds, and sloughs provided rich and diverse ecosystems (Brown and Vierra 1983). The exploitation of fresh water mussels became important. Large numbers of discarded mussel shells in camp middens produced large shell mounds, a tradition that would continue into the Late Archaic. The Shell Mound Archaic, as these cultures are often referred, suggest cultural affiliations with traditions in the Southeast along the Tennessee and Cumberland rivers where shell mound villages appear during the Middle Archaic period (Lewis and Kneberg 1959).

Preliminary information from a deeply stratified site, 36AL480, being investigated along the upper reaches of the Ohio River near Leetsdale, Pennsylvania, indicate human populations were repeatedly utilizing resources along the Ohio River floodplain there as early as 8,000 years ago (http://www.lrp.usace.army.mil/lmon.htm). Geomorphological studies undertaken in association with this site point to the area being an island in the Ohio River during the Middle Holocene. A 1998 archaeological and geological assessment of the Ohio River Islands National Wildlife Refuge classified Ohio River islands into three different types with regard to CR: 1) islands with sediments having recent origins not likely to contain prehistoric archaeological sites; 2) islands with Holocene sediments likely to contain historic archaeological sites close to the surface and deeply buried prehistoric sites; and 3) islands which contain a core area of Pleistocene sediments overlaid by shallow Holocene age sediments, which are likely to contain prehistoric and historic resources closer to the surface (USFWS 2000). Information on island formation is relevant to what kinds of prehistoric sites could exist on individual islands. For example, if an island contains only late Holocene sediments (i.e., 4,000 years before present to present), then sites from earlier prehistoric periods would not exist on the island.

Large-scale excavations by Southern Illinois University-Carbondale at the Carrier Mills Archaeological District in Saline County, Illinois uncovered a major late Middle Archaic occupation dating from approximately 4000 to 3000 B.C. at the Black Earth site (Jefferies and Butler 1982). Subsistence data indicate the site was probably a semi-permanent base camp. The site was characterized by a deep midden, abundant floral and

faunal remains, and numerous human burials (Jefferies 1987; Jefferies and Butler 1982). The plant foods exploited by the Middle Archaic occupants of the site include fruits, wild bean, and a wide range of nut species, most notably hickory nuts and acorns. In contrast to many Middle Archaic sites in areas to the southeast and northwest, however, the Black Earth site contained no evidence of the early cultivation of plants such as sumpweed, squash, and gourd. The faunal assemblage from the Black Earth site includes the remains of white-tailed deer, elk, turkeys, various marsh birds, reptiles, amphibians, and fish. White-tailed deer remains dominate the faunal assemblage, and provides evidence of the year-round hunting of this animal. Fish were an especially important subsistence resource, suggesting the exploitation of the swampy lakes surrounding the sites in the Carrier Mills Archaeological District was a major site location criterion for the Middle Archaic occupants of this area. Excavations at the Rose Hotel in Hardin County, Illinois recorded Middle Archaic use of this bluff area above the Ohio River (Wagner and Butler 1999). Horseshoe Lake in Alexander County, Illinois at the confluence of the Ohio, Cache, and Mississippi rivers has also provided information on the Middle Archaic in that area (Koldehoff and Wagner 2002).

Much of our current knowledge about this period has been derived from investigations of Middle Archaic sites in West Virginia and the Carolinas. Little is known about the Middle Archaic occupation of the central Ohio River Valley, and this has been confined to the recovery of isolated artifacts or the identification of Middle Archaic manifestations in multicomponent sites. A similar lack of Middle Archaic data has been noted regionally (Purtill et al. 2001; Adovasio et al. 1998; Raber et al. 1998).

The beginning of the Late Archaic period generally coincides with the end of the Hypsithermal. The regional climate moderated, rainfall increased, and conditions in the Midwest became similar to present conditions. The Late Archaic period demonstrates intensive adaptations to ecological niches not exploited earlier (C. Chapman 1975). It has been suggested that the Late Archaic represents the climax of the long Archaic hunter/gatherer traditions in the Midwest that were replaced by strategies favoring the intensive exploitation of local resources. Caldwell (1958) has referred to this subsistence strategy as the primary forest efficiency of the Late Archaic people with extensive shellfish exploitation and nut collection and processing. Several phenomena that characterize the following prehistoric cultural periods can be traced to the Late Archaic. During this period the emergence of a plant-forager economy, incipient gardening, increased sedentism, and population growth set in motion trends that would eventually lead to complex and dynamic political and social systems in the Midwest. While gardening is thought to have added to the subsistence strategy, the question over the appearance of domesticated forms of cucurbits and native starchy seed plants remains argued. Kay et al. (1980) have reported squash at the Phillips Spring site in southwestern Missouri in a Late Archaic context. Winters (1969) also reported a fragment of squash from the Riverton site in Crawford County, Illinois.

Many Middle Archaic projectile point forms pervaded into the Late Archaic. Tool kits became more diversified, and the groundstone and worked bone industries became fully developed (Sieber et al. 1989). Extensive trade networks were developed as marine shell, copper from the Great Lakes, steatite from the Appalachians, and other exotic materials arrived in the Ohio River Valley (Sieber et al. 1989). Cultural material from the period indicates that cultural change was taking place throughout the Late Archaic and became more pronounced during the later stages of the period. For unknown reasons, the

use of locally available, high grade cherts declined as lower quality cherts, including glacial gravels, were exploited. The quality of the chipped-stone industry also declined (Seeman 1975). People moved out of the main river valleys, at least seasonally, and began to exploit upland resources. Suggestions are that small, intensively occupied, seasonal camps were established along small upland streams and springs (Munson 1988). So intense was the exploitation of aquatic resources during the Late Archaic that Dragoo (1976) has referred to it as the Riverine Archaic tradition. Large quantities of mussel shells, discarded over time in camp middens, produced large shell mounds on which villages and camps were located. These Late Archaic shell mound sites are common along the Ohio River and tributaries.

Late Archaic sites in southwestern Indiana have been grouped into the French Lick phase (3,500–1,500 B.C.) (Munson and Cook 1980). This phase represents a period of intensive occupation in southwestern and south-central Indiana. These sites are located in a variety of environments from main stream valleys and secondary drainages to dry dissected uplands and rockshelters (Sieber et al. 1989). The settlement pattern suggests summer and fall base camps located on perennial streams. Fall and winter hunting camps and large summer camps were located next to major rivers where the procurement of large quantities of river mussels produced shell midden sites (Sieber et al. 1989). This suggests a subsistence model involving a broad-based economy involving hunting/collecting and harvesting of aquatic resources. This model is similar to that proposed by Winters (1969, 1974) for the Midcontinent Archaic tradition. Other Late Archaic sites that have contributed to the prehistoric record of Indiana include the Bono site in Lawrence County (Tomak 1983, 1984), the Crib Mound in Spencer County (Kellar 1956; Brinker 1982), the McCain site in Dubois County (Miller 1941), the Prairie Creek site in Daviess County (Munson 1980), and the Turpin site in Gibson County (Morrison 1975).

In the lower Wabash River Valley, its major tributaries, and extending into southern Indiana, a cultural manifestation appeared toward the end of the Archaic that has been defined as the Terminal Late Archaic Riverton culture (Winters 1969). The majority of our information on these people comes from excavations and testing conducted by the Illinois State Museum in the early 1960s at the Riverton site (11-Cw-170) and the Swan Island site (11-Cw-319) in Crawford County, Illinois, and the Robeson Hills site (11-Lw-1) in Lawrence County, Illinois. The Riverton culture is represented by a radical change in lithic technology from that identified with the earlier Archaic lithic industry. Very small projectiles such as the Trimble, Merom, and Robeson points were typically produced from heat-treated chert pebbles found in glacial gravels. Deep, shell-rich middens, characteristic of base camps, provided excellent site preservation so that bone tools including hide scrapers, flaking tools, bone awls, and shuttles have been preserved (Winters 1969). Prepared clay platforms, interpreted as the floors of structures, and clay plugs on deep storage pits both suggest a degree of sedentism. Well-preserved burials indicating different burial methods and small caches or bundles of grave goods found with some burials may suggest a form of social differentiation had developed in these societies. Important work has been conducted in southern Indiana on these Late Archaic sites. Anslinger (1986) conducted a much needed analysis of the lithic assemblage of the Wint site (12B95) in Bartholomew County, Indiana. His work involved an examination of the lithic procurement strategy as well as heat treatment and chipped-stone tool reduction technology. This work also has provided a source book of sorts that compiles references and information on the Riverton culture that has came to light since the work of Winters in the 1960s. A review of relevant data on the settlement and subsistence strategies of the

Riverton people suggested to Anslinger that while some modifications to the model proposed by Winters are necessary, the basic dispersed and linear model is supported by recent evidence. The clustering of Riverton villages/camps along major river valleys and prominent tributaries suggests a settlement and resource procurement strategy different from that known for earlier Archaic manifestations (Anslinger 1986). Additional information on Riverton sites in Gibson and Posey counties, Indiana, can be found in Higgenbotham (1983).

In southern Illinois, Late Archaic components are recognized by the recovery of Trimble, Merom, Karnak, Saratoga, and Cypress points. Late Archaic occupations were identified in the Carrier Mills Archaeological District (Jefferies and Butler 1982) and along the Ohio River (Butler et al. 1979). A recent site excavated along the Ohio River in Illinois that contained a Late Archaic component was the Rose Hotel (Wagner and Butler 1999). The Horseshoe Lake area near the confluence of the Mississippi and Ohio Rivers also has a Late Archaic presence (Koldehoff and Wagner 2002).

For the mid-Ohio River Valley, several contemporary, geographically distinct Late Archaic complexes or phases have been forwarded (Purtil et al. 2001). For southwestern Ohio, Vickery (1980) has identified the Central Ohio Valley Archaic (2750 B.C. to 1750 B.C.) and Maple Creek Phase (1750 B.C. to 1000 B.C.). The Central Ohio Valley Archaic is marked by a predominance of McWhinney Heavy-stemmed points, lower frequencies of Laurentian Archaic types (e.g., Brewerton series), hafted scrapers, and various ground stone tool types. These sites tend to be large base camps concentrated along major river systems (Purtil et al. 2001). Large numbers of roasting pits, hearths, storage pits, and burials are known to occur at these locales. The Maple Creek Phase appears in southwestern Ohio at the end of the Central Ohio Valley Archaic approximately 1750 B.C. This phase is closely related to Riverton Cultures to the west (Winters 1969) and is characterized by Merom/Trimble points and a micro-tool industry. Settlement patterns appear similar to preceding Late Archaic phases (Purtil et al. 2001).

The picture in southeastern Ohio is considerably more confusing regarding the Late Archaic (Purtil et al. 2001). Phases (e.g., Dunlap Phase) are poorly defined and are often based on nonintensive surface collections without excavations (Murphy 1975; Purtill et al. 2001). Artifacts are usually associated with the Laurentian Archaic Tradition of New York such as Brewerton Corner-Notched and Side-Notched points (Murphy 1975; Cinadr 1985; Purtill et al. 2001). Laurentian Archaic sites date from 3200 B.C. to 2000 B.C., although data from the Davisson Farm Site in Lawrence County, Ohio, has suggested that these point types may have been in declining use well past 1000 B.C. (Purtill et al. 2001; Purtill 2002). Late Archaic manifestations in southeastern Ohio appear influenced, to varying degrees, by neighboring complexes, especially Riverton-like groups to the west and Laurentian Archaic-like groups to the north (Purtill et al. 2001).

The Terminal or Transitional Archaic period (2000 B.C. to 1400 B.C.) represents the last manifestation of the Archaic period for Ohio (Purtil et al. 2001). Also poorly defined, these late cultures have seen little attention. It is unclear at this time whether this time period is a transition between the Late Archaic and Early Woodland or whether it is a distinct period (Purtil et al. 2001).

In north central Kentucky, the Terminal Archaic is represented by the Cogswell phase (Ison 1988; Ledbetter and O'Steen 1991) which dates between ca. 1250 to 800 B.C.

Diagnostic projectile points include Cogswell, Buck Creek Barbed, Wade, Little Bear Creek and McIntyre-like points and ceramic may appear at the end of the phase (Purtil et al. 2001). Feature types include charcoal-filled/lined pits; fire-cracked rock-lined pits, and chert filled cache pits. A circular feature cluster at the Grayson Site (Ledbetter and O'Steen 1991) suggests structures were in use. Subsistence data from carbonized plants include nutshell (primarily acorn and hickory), wood charcoal (hickory, oak, and ash), and seeds (cultivated sumpweed, wild sunflower, squash, knotweed, goosefoot, maygrass, and ragweed). Data from the Cloudsplitter Shelter (Cowan et al. 1981) suggest that during the Cogswell phase, incipient cultivation of plants was well under way. Faunal remains are not common in the site settings (likely due to poor preservation); however, mammals such as bear, deer, squirrel, rabbit, and woodchuck comprise the bulk of the edible meat with turtles, turkey, and grouse making up most of the remainder. Fish and mussels are minimal contributors according to the data presented (Ledbetter and O'Steen 1991; Purtil et al. 2001).

Within the upper Ohio River Valley the recent excavations at site 36AL480 in Leetsdale, Pennsylvania, contained both Late Archaic and Terminal Late Archaic components. These deposits were recorded from 1 m to 4 m below the present ground surface. The Transitional Archaic period appears to consist of two distinct groups a late Transitional Archaic at ca. 3100 BP and an early Transitional Archaic at ca. 3400 BP. A series of Late Archaic camps was identified that date to ca. 5500 BP. Specific diagnostic material recovered from the late Transitional Archaic groups consists of Fishtail and Forest-notched points and pottery. Diagnostic material from the earlier Transitional Archaic groups consisted of Broadspears and small points. The steatite was recovered from levels associated with these groups as well. Late Archaic materials consisted of Brewerton side-notched, corner-notched, and eared points. Little faunal and floral material was recovered from the features at 36AL480. This site may have been a series of short duration camps. Based on all of the evidence, it was occupied from Middle Archaic through Early Woodland (http://www.lrp.usace.army.mil/lmon.htm). Based on excavations it appears that the Late Archaic is the best represented period at the site where excavations took place. Features recorded consisted of basin shaped pits with numerous cracked rock. Also present were stains that appeared to be surface fire hearths. The Scenery Hill site, a semi-permanent or permanent base camp within the upper Ohio River Valley, was excavated by East et al. (1996). It appears that there were defined activity areas at the site based on the excavations. Similar features were recorded at this site as at 36AL480. Features from the Scenery Hill site contained hickory and black walnut.

Cultural changes thought to have occurred during the Terminal Late Archaic period include an increased emphasis on ceremonialism. Projectile points are typically well made and exhibit skilled craftsmanship. Point types associated with this time period include the Adena Ovate-base and Turkey Tail points, along with precursors of the Early Woodland stemmed points. Turkey Tail points were widely distributed in eastern North America and have been found in caches and burial contexts. The Late Archaic period represents the blossoming of a great diversity of cultural traditions throughout eastern North America. This recognized cultural differentiation was based primarily on adaptations to stabilized regional and local environments "that made maximum use of all resources within restricted areas" (Dragoo 1976; Purtill et al. 2001). Toward the end of the Late Archaic period and continuing into the beginning of what is known as the Early Woodland period, a mortuary tradition occurred throughout the mid-Ohio River Valley that was characterized by the placement of shaft graves into glacially derived rises. Known as the Glacial Kame

manifestation, these cemetery sites have often produced evidence of long-distance trade in the form of copper from the Upper Great Lakes and conch shell from the Florida Keys. Habitation sites associated with these mortuary complexes have yet to be defined (Purtill et al. 2001).

The Woodland period is characterized by a trend toward increased sedentism, intensified horticultural activity, expanding regional exchange networks, and the elaboration of ceremonial activities and mortuary practices (Griffin 1967). The origin of these trends can be traced to the Late Archaic, but elaboration of cultural elements became the hallmark for the time. These developmental trends form the basis for distinguishing the Early, Middle, and Late Woodland substages. Regional variations in the timing and extent to which these traditions were expressed, however, make this tripartite subdivision difficult to employ in certain areas. The Early Woodland period is usually demarcated by the introduction of pottery manufacture; the timing of its appearance seems to vary spatially across the landscape. For instance, in the upper Ohio River Valley, thick-walled coarse-tempered ware first appears around 1,000 B.C., whereas in the lower valley in Indiana and Illinois, dates suggest pottery did not appear until around 500 B.C. (Seeman 1986). Projectile points typically associated with the Early Woodland period include contracting stem varieties such as the Adena Stemmed and the notched Turkey-tail types. Highly crafted ground and polished stone items such as gorgets, amulets, celts, and tubular pipes were also made (Sieber et al. 1989).

In contrast to the Late Archaic settlement pattern, Early Woodland occupations in the Midwest are typified by relatively small, short-duration camps located adjacent to specific environmental locales. This pattern suggests that small social groups using seasonally occupied, specialized extraction camps were exploiting resources within defined localities (Emerson and Fortier 1986; Roper 1979; Seeman 1986). Rockshelters continued to be used and possibly served as hunting camps (Sieber et al. 1989). Evidence exists that gardening increased in importance as native starchy seeds such as maygrass (*Phalaris caroliniana*), knotweed (*Polygonium erectum*), goosefoot (*Chenopodium bushianum*), and marshelder (*Iva annua*), along with sunflower (*Helianthus* sp.) and gourds (*Cucurbita* sp.) added to the traditional hunting/gathering economy.

The Adena Culture is the best known Early Woodland complex for the Ohio River Valley (Purtill et al. 2001). The burial mounds associated with this cultural manifestation are typically small and are usually located on either high terraces, bluffs, or within the valley bottoms (Murphy 1975; Abrams 1992; Carskadden and Morton 1997; Waldron and Abrams 1999). Adena mounds have long been the subject of archaeological investigations (Purtill et al. 2001). Adena mounds are conical in shape and often contain various structural elements including bark lined crypts, layered mound construction, extended burials, cremations, and associated grave furniture (Purtill et al. 2001). Many were accretional and attained great size, such as the Grave Creek mound in Ohio that is 21 m high by 90 m in diameter (Seeman 1986). Murphy (1975) also notes that stone mounds, which are restricted to hilltop locations, appear by the end of the Early Woodland period. Recent GIS based analyses of distributional patterns of Adena-aged mounds suggests a high degree of intersite visibility potentially signifying inter-hamlet communication (Waldron and Abrams 1999; Purtill et al. 2001).

Adena habitation sites, on the other hand, are usually small villages or hamlets located along low terraces and in the floodplains of stream valleys (Purtill et al. 2001).

Abrams (1992) has proposed an Adena Settlement system that consisted of dispersed clusters of 1 to 2 mounds associated with small habitation sites. In the Muskingum Valley, Carskadden and Morton (1997) indicate that "Adena hamlets covered areas ranging from .28 to .32 ha, with a scattering of postmolds, usually in no readily identifiable pattern, in the immediate vicinity of cluster of cooking/thermal features...there is no real indication that these sites were occupied for great lengths of time." (Purtill et al. 2001).

Recent research in northern Kentucky at the West Runway Site (Bergman et al. 1998) provides some of the best information regarding the earliest ceramic producing Early Woodland (pre-Adena) cultures. Importantly, this pre-Adena site was characterized by a co-association of Kramer projectile points and Fayette Thick ceramics as early as 770 B.C. (Purtill et al. 2001). In southeastern Ohio, Fayette Thick ceramics derive from dated contexts consistently between 1000 B.C. to 700 B.C. and have been dated as early as 1560 B.C. at Rais Rock Shelter in Jackson County, Ohio (Murphy 1975; Purtill et al. 2001).

A series of excavations at the Boudinot #4 Site (33At521) and Boudinot Farm (33At41/80) by Abrams (1992) have provided some of the best examples of Early Woodland hamlets for the region (Purtill et al. 2001). The site is characterized by a wide range of domestic tool types including hammerstones, pestles, a mano, Robbins points, and thick-walled ceramics (likely Adena Plain) (Purtill et al. 2001). Post molds and cooking/roasting pits were also documented. Seasonal data suggest that these occupations were not occupied year round. Abrams (1992) suggests that these sites acted as warm weather locales intermittently being occupied from mid-spring through mid-fall.

Several pottery types are associated with Adena, including Adena Plain and Montgomery Incised (Chapman and Otto 1976). Projectile point types include large, stemmed triangular blades and leaf-shaped blades. Murphy (1975) notes that iron oxide materials such as hematite play an increased role for the manufacture of mortuary goods. There is evidence that the Early Woodland diet was supplemented by the domestication of various native and non-native cultigens such as sunflower, chenopodium, various carbonized nut species, squash, and cultivated maygrass (Purtill et al. 2001). However, it is now known that the domestication of plant foods had its antecedent during the Late Archaic (Purtill et al. 2001).

The Crab Orchard ceramic tradition is presently recognized as an expression of the Early and Middle Woodland periods in southern Illinois. In southern Illinois the Early Woodland period remains poorly understood. The earliest Woodland sites usually contain a few thick, crude, cordmarked or fabricmarked potsherds that have coarsely crushed grit temper and reddish paste colors as well as stemmed projectile points assigned to the Adena, Kramer, or Cypress types (Butler and Jefferies 1986; Denny 1972; Moffat et al. 1992). Cypress points are also found at Late Archaic and Middle Woodland sites (Moffat et al. 1992; Woods and Denny 1980). Unlike other areas of the Midwest, the interior of southern Illinois has yielded no Early Woodland burial mounds. Work at Horseshoe Lake in Alexander County, Illinois, at the confluence of the Ohio, Mississippi, and Cache rivers has a documented Early Woodland presence, (Koldehoff and Wagner 2002) as does, the Rose Hotel in Hardin County, Illinois (Wagner and Butler 1999). In general, Early Woodland life ways in this area do not seem to have differed much from those characteristic of the Late Archaic period.

In southwestern Indiana the uplands and smaller river valleys appear to have been virtually abandoned during this time, with the populations concentrating along major river valleys and their tributaries (Sieber et al. 1989). Rockshelters continued to be used and possibly served as hunting camps (Sieber et al. 1989). The first pottery in central and southern Indiana is similar to the Marion Thick, Fayette Thick, Baumer, and early Crab Orchard types (Dragoo 1963, 1976; Farnsworth and Emerson 1986; Jefferies 1987; Kellar 1983). This pottery is characteristically thick-walled, coarse-tempered, cordmarked, fabricmarked, or plain. Vessel shape consists of a simple, flat-bottomed jar. Marion Thick ceramics appear in the area around 500 B.C. (Sieber et al. 1989).

In the upper Ohio River Valley Adena mounds occur but not as commonly as within the middle Ohio River Valley and below (Weed 2004). Early Woodland site types in the upper Ohio River Valley are dispersed across the landscape and larger sites, such as villages and earthworks, seem to occur most frequently in lowland or valley settings (Weed 2004). It therefore appears that the Early Woodland settlement system was focalized in the lowlands with a dispersed system of smaller specialized sites (Weed 2004). Early Woodland house forms in this area were not standardized and include oval, round, and rectanguloid shapes (Weed 2004). It needs to be remembered that in Pennsylvania there are two Early Woodland groups present: the Adena and the indigenous Late Archaic groups.

The developmental trends characteristic of the Woodland tradition are most strongly expressed in many regions of the Midwest during the Middle Woodland Hopewellian stage. The Hopewellian stage within the Ohio River Valley is exemplified by the Hopewell of southern Ohio. Hopewell cultural groups lived throughout the Ohio River Valley in southern Illinois, southern Indiana, southern Ohio, northern Kentucky, northern West Virginia, and western Pennsylvania. Hopewell is most prominently marked by the appearance of large village and ceremonial sites containing geometric earthworks and conical burial mounds, an emerging pattern of social status differentiation (Moffat 1990), and a remarkable expansion of interregional exchange (Brose and Greber 1979; Muller 1986). In addition to the Ohio Hopewell core area, an important expression of the Hopewell complex is also represented by a late Hopewellian variant in the lower Wabash-Ohio River Valley (Brose and Greber 1979). The Hopewell exchange network, or Hopewell Interaction Sphere (Struever and Houart 1972), linked the diverse Middle Woodland societies of these regions during the period from about 100 B.C. to 350 A.D.

Large quantities of exotic materials, stylistic concepts, and, to a lesser extent, finished trade goods, were exchanged through the Hopewell Interaction Sphere. Hopewellian trade items include such exotic materials as obsidian from Wyoming, mica sheets from the Appalachian Mountains, copper from the western Great Lakes, and marine shell from the Gulf of Mexico, as well as finished goods such as clay figurines, Havana trade vessels, stone platform pipes, copper and silver panpipes, copper breastplates, and copper reels (Brose and Greber 1979; Struever 1964). These trade items are usually found in association with burials. The occurrence of these items at a Middle Woodland site is regarded as evidence of participation in the Hopewellian exchange network or of Hopewellian contact.

Several less exotic markers of Hopewellian influence include certain distinctive ceramic decorative techniques, corner-notched points of the Snyders type, high-quality, nonlocal chert, and blades and conical cores. Locally made pottery exhibiting elaborate

zoned dentate-stamped, rocker-stamped, and incised-line designs is typical of Hopewellian influenced sites (Griffin 1967). The wide-spread occurrence of these Hopewellian decorative elements indicates that "stylistic concepts...were moving through the [Hopewellian exchange] network" (Struever 1964) together with raw materials and finished goods. Similarities in the burial programs of regionally distinct Hopewellian societies provide additional evidence that the Hopewell Interaction Sphere served as a channel for the dissemination of both ideas and trade items (Struever 1964). The spread of blade core technology may represent another example of this process (Morrow 1988).

It has long been realized that the Middle Woodland societies participating in the Hopewell Interaction Sphere represent a diverse group of regionally distinct cultural traditions rather than a single, panregional Hopewell culture (Griffin 1979; Struever 1964; Struever and Houart 1972). These Middle Woodland regional expressions are distinguishable on the basis of their adaptation patterns, formal aspects of the utilitarian component of their material culture, and their separate histories. Consequently, artifactual evidence of participation in the Hopewell phenomenon generally appears as an overlay on the base culture.

Evidence of increased sedentism, intensified horticultural activities, increased population aggregation in major river valleys, and a concomitant reduction of the resource procurement range is present in the archaeological record of many communities participating in the Hopewell phenomenon (O'Brien 1987). Therefore, establishment of exchange relationships with groups located in other subsistence resource areas can be viewed as a response to the increased risks of resource shortfalls attending a subsistence/settlement strategy involving decreased residential mobility and localization of resource procurement activities (Morrow 1988). From this perspective, exchange of exotic trade items appears to have served the function of establishing and stabilizing exchange relationships with distant groups to ensure access to alternate subsistence resources in times of emergency or famine.

A model of the structural organization of the Hopewell Interaction Sphere has been developed by Struever and Houart (1972). Two types of sites, regional transaction centers and local transaction centers, are described as focal points in the distribution of Hopewellian materials and goods. Regional transaction centers are large, complex sites containing burial mounds and large amounts of Hopewellian materials and goods. These sites are regularly distributed along the major waterways throughout the Midwest. Regional transaction centers served as points of entry for Hopewellian trade items entering regional networks from other regions and as exit points for trade items leaving local networks for other regions (Morrow 1988). The smaller, local transaction centers functioned as distribution points within the regional network, both for Hopewellian materials and goods produced within the local network and those coming from the regional transaction centers (Struever and Houart 1972).

Two Middle Woodland cultural traditions are recognized in Illinois: the Crab Orchard tradition, which is centered in southern Illinois and encompasses adjacent portions of Indiana, Kentucky, and Missouri, and the Havana tradition, which is centered in the Illinois River Valley and extends over much of central and northern Illinois north of the Crab Orchard region (Butler and Jefferies 1986; Fortier et al. 1984; Griffin 1967; Struever 1965). The Crab Orchard and Havana traditions are distinguished by basic differences in ceramic decorative styles and vessel forms, as well as, by differences in adaptation patterns

(Hargrave et al. 1991; Struever 1964). The Middle Woodland societies associated with these two traditions also differ in the extent to which they participated in the Hopewell phenomenon.

Characteristic Middle Woodland ceramics in southern Illinois are grit-tempered and fabricmarked, but some cordmarked vessels are present. Early Middle Woodland ceramics are typically undecorated but have darker pastes and are better fired than Early Woodland vessels. Late Crab Orchard pottery commonly consists of thin, well fired, fabricmarked vessels that are decorated with rim nodes. Vessels with smoothed exteriors that are decorated with incised or stamped designs are also occasionally found. Well-made, corner-notched projectile points (Snyders or Affinis Snyders), Cobden biface blanks, and formal, unifacial scrapers are also commonly found at Middle Woodland sites in southern Illinois (Snyder et al. 2002).

Parker (1990) describes Crab Orchard subsistence patterns as representing a generalized adaptive strategy focused on hunting and nut gathering, with the cultivation of several cultigens, principally indigenous starchy seed cultigens, playing a minor supplemental role. Blanton (1989) notes there is general agreement among area researchers that the Crab Orchard pattern of seasonal movement within major environmental zones involved the creation of few permanently occupied sites.

One large regional center of the Hopewell Interaction Sphere within the lower Ohio River Valley represented by the Crab Orchard tradition in southern Illinois is the Wilson-Hubele-Rutherford complex in the lower Wabash-Ohio River Valley. The Wilson Mound Group and Hubele village sites are located on the Wabash River in eastern White County, Illinois. The Rutherford Mound overlooks the confluence of the Saline and Ohio Rivers in eastern Hardin County, Illinois. The Rose Hotel in southern Hardin County was found to have an intensive occupation during the Early to Middle Woodland Crab Orchard period when a series of very deep storage pits and other features were constructed at the site (Wagner and Butler 1998). At the confluence of the Ohio, Mississippi, and Cache rivers at Horseshoe Lake in Alexander County, Illinois, Crab Orchard Middle Woodland sites have also been recorded, (Koldehoff and Wagner 2002) as well as, up the Cache River Valley (Howe et al. 1994).

The most remarkable manifestation of the Wabash Hopewellian complex is the Mann site in Posey County, Indiana (Kellar 1979). This site is located approximately 40 km southeast of the Wilson Mound Group. The Mann site has been characterized as "the most important link between the southern Ohio Hopewell sites and the Havana-Hopewellian sites in the Illinois Valley" (Griffin 1979). This site covers an area of at least 175 ha and contains the largest concentration of geometric earthworks and mounds outside of Ohio (Griffin 1979). Aside from the circular earth embankments enclosing two of the Wilson site mounds, the Mann site earthworks are the only geometric earthworks recorded in the region (Kellar 1979). Ceramics from the site display a variety of Hopewellian decorative motifs, including incised and paddle-stamped pottery whose designs show affiliation with Marksville in the lower Mississippi River Valley and Swift Creek-Santa Rosa groups in the Southeast (Kellar 1979). In addition to Hopewellian trade goods and Hopewellian-influenced ceramics, a large amount of obsidian and a large number of locally-made clay figurines have been recovered from the Mann site (Kellar 1979). Blades and blade cores are also abundant, as is nonlocal chert (Kellar 1979).

Another important Mann phase site, the Mount Vernon site (12Po885), is located approximately 8 km west of the Mann site. Discovered during road construction, the site represents a ceremonial and burial complex that contains a loaf-shaped mound, the GE mound, that is one of the five largest Hopewell mounds in the Midwest (Ruby 1993). Large bifaces, copper earspools and celts, and obsidian blades indicate the inhabitants of the Mount Vernon site were actively involved in the Hopewell Interaction Sphere. The results of ongoing research at the site continue to provide new insights into the ideology, mortuary customs, and ceremonialism associated with the Hopewell phenomenon (Ruby 1993; Tomak 1990).

Crab Orchard sites of the southern Illinois interior present little evidence of participation in the Hopewell exchange network (Muller 1986). Muller (1986) suggests that the limited participation of Crab Orchard populations in the Hopewell exchange system reflects a cultural conservatism that may relate to differences in the economies and organization of Hopewellian and Crab Orchard societies.

The investigations by Cole et al. (1951) in the vicinity of the Kincaid Mounds on the lower Ohio River recovered additional Middle Woodland artifacts that appeared to be stylistically similar to Maxwell's (1951) Crab Orchard material. However, Cole et al. (1951) defined another cultural complex, the Baumer focus, to include this material. Whether Middle Woodland sites in the eastern Shawnee Hills are more closely related to Baumer or to the Crab Orchard culture is an unresolved problem (Butler and Jefferies 1986). Middle Woodland remains recovered during the Carrier Mills project were called Crab Orchard rather than Baumer (Jefferies 1987). Recent excavation at the Kincaid Mounds by the Center for Archaeological Investigations at Southern Illinois University-Carbondale recovered evidence of Baumer components (Brian Butler personnel communication 2004; Butler and Welch 2003). He stated that, "From the beginning we were aware that some Middle Woodland occupation would be present within the area of investigation, but we were surprised by the extent and intensity of it, as evidenced by a high density of large pit features. The old Baumer living surface is differentially preserved over the area, with much of it removed under the ridge crest Mississippian mound construction. Elsewhere, the layer appears to have been incorporated to various degrees within the Mississippian occupation zone. The many pit features associated with this occupation are, however, intact, and these are mostly large pits with a high refuse content. Clearly, if it were ever doubted, the front slope of Avery Lake at Kincaid was a major Baumer habitation site."

In the later part of the Middle Woodland, the Allison-Lamotte culture appears in the lower Wabash River Valley (Pace 1974; Winters 1967). This culture was centered along the Wabash River and its major tributaries in Indiana and Illinois. The culture is characterized by the Lowe Flared Base; lamellar blades; sand- and grit-tempered, cordmarked, plain, and check stamped Embarrass Series pottery; and permanent to semi-permanent villages along major rivers (Pace and Apfelstadt 1980). Wyandotte chert was widely used by these groups in the Wabash River Valley and may have been obtained through some yet unknown, elaborate exchange system. While some Hopewell-like ceramics have been found at Allison-Lamotte sites, the degree of association–direct, indirect, or none–with Hopewell centers such as the Mann site is presently unknown.

In the middle Ohio River Valley the predominant Middle Woodland culture is known as the Hopewell Tradition (Prufer 1964). It is characterized by elaborate geometric

earthworks, enclosures, and mounds that are often associated with multiple burials and a wide array of exotic ceremonial goods. Materials used in the manufacture of these ceremonial items were acquired from various regions of North America: at least six species of marine shell from the Atlantic and Florida Gulf coasts; barracuda jaws, turtle shells, shark and alligator teeth from Florida; mica from southwestern North Carolina; chlorite from the southern Appalachians; meteoric iron from several sources; native copper from Lake Superior deposits; and silver from the vicinity of Cobalt, Ontario. Exotic lithic materials include large quantities of chert from Harrison County, Indiana; obsidian from the Yellowstone area in Wyoming; and Knife River chalcedony from North Dakota (Griffin 1978). Diagnostic lithic artifacts include thin, expanding base points, leaf-shaped blades, prismatic blades and associated polyhedral cores. Ceramics were manufactured with grit or limestone tempering and have plain or cordmarked surfaces (Purtill et al. 2001).

Historically, data on Illinois Hopewell settlement systems has been more complete than Ohio counterparts (Purtill et al. 2001). Over the past 20 to 30 years, survey and excavations within several drainage systems in central and southern Ohio have generated abundant settlement evidence for Ohio Hopewell populations. A lack of evidence for long-term, residential populations within ceremonial complexes has been argued recently for Ohio (Dancey and Pacheco 1997). This model argues for dispersed farmsteads that shared a central ceremonial center within each watershed. Investigations at the Jennison Guard site in southeastern Indiana (Kozarek 1987) and the various Murphy sites near Columbus, Ohio (Dancey and Pacheco 1997) appear to support the dispersed farmstead model of Ohio Hopewell settlement. It is argued that these farmsteads/hamlets are parts of a seasonal settlement system that was based on low group mobility with populations residing in good food resource producing areas throughout the year (Purtill et al. 2001).

In southeastern Ohio, a considerable amount of Hopewell settlement data has derived from the central Muskingum Valley (Purtill et al. 2001). These data suggest several trends including evidence of Hopewell hamlet clustering dispersed along floodplain locations, a distribution noted elsewhere (Abrams 1992). Carskadden and Morton (1997) argue that previous Adena period occupations often were re-used by Hopewell groups demonstrating a high degree of continuity between Early and Middle Woodland societies (Purtill et al. 2001).

In the upper Ohio River Valley the Middle Woodland is defined as a transition from the Adena to the Late Woodland Monongahela (Weed 2004). As with the middle Ohio River Valley the settlement patterns of Middle Woodland groups in the upper Ohio River Valley are poorly understood. While the Middle Woodland groups are using the same topographic settings as the Early Woodland groups, the Middle Woodland groups use of the floodplain significantly increases. Sites of the Middle Woodland period remain poorly investigated likely because of the poorly defined temporal parameters for the period in the upper Ohio River Valley (Weed 2004).

The end of the Middle Woodland period was marked by a reduction in interregional trade, a decrease in the complexity of ceremonial/mortuary practices, and a reduction in the elaborateness that marked the period. A traditional view has been that the Late Woodland was a time of de-evolution in the cultural development of the Midwest. However, important and dynamic cultural and organizational changes were taking place that set the stage for the development of the Mississippian period in the region. Some of these

changes include changes in ceramic technology, the development of an agricultural economy, and the introduction of the bow and arrow.

Subsistence during the Late Woodland period was characterized by an intensive exploitation of local wild plant resources, supplemented by a variety of domesticated seed crops and meat resources. Maize gardening continued through this period but appears to have been only a minor garden crop (Ford 1974, 1977; Fritz 1992; Kelly et al. 1984). Gardening probably consisted of a starchy seed complex (Ford 1981) of goosefoot (*Chenopodium bushianum*), knotweed (*Polygonium erectum*), smartweed (*Polygonium* sp.), and maygrass (*Phalaris caroliniana*). Through the Late Woodland period, gardening became more important as suggested by the relocation of villages to floodplains with highly productive soils and the increased size and frequency of pits (Kelly et al. 1984). It was perhaps the increased importance of garden crops that promoted an increase in population throughout the period and a nucleation of the population into larger, more permanent villages (Sieber et al. 1989). In addition, evidence for tobacco, squash, gourd, and maize has been documented. There appeared to be a rise in maize consumption during the later stages of the Late Woodland period and also an increase in hunting of large mammals (e.g., deer) is evidenced during this period (Purtill et al. 2001).

The Late Woodland period in the middle Ohio River Valley is characterized by technological advances, increased sedentism, and the escalating dependence on cultigens as a subsistence base. In many ways, the Late Woodland period can be viewed as a cultural continuum from the proceeding Middle Woodland (Hopewell) period minus the elaborate burial ceremonialism. Traditionally, fieldwork on Late Woodland sites focused on delineating regional phases, complexes or traditions such as the Cole Complex (Baby and Potter 1965), the Peters Phase (Prufer and McKenzie 1966), the Chesser Phase (Prufer 1967), and the Intrusive Mound Complex (Seeman 1980, 1992; Purtill et al. 2001).

During the early Late Woodland period, large, nucleated settlements in floodplain and terrace settings appear for the first time within the middle Ohio River Valley. Settlements located in environmentally rich ecological zones, such as within the Little Miami River Valley, appear to have been occupied year round and continuously for several generations; whereas, other sites appear to have been inhabited for shorter periods of time (Purtill et al. 2001). Ditches or earthen embankments have been documented encircling several larger sites such as the Zencor and Water Plant sites in Franklin County, Ohio. These features, along with the concomitant rise in lethal projectile wounds, are thought to represent a rise in regional hostilities not witnessed in preceding Middle Woodland times. By the later stages of the Late Woodland period, large settlements are no longer established as local populations again concentrate in smaller, dispersed sites (Purtill et al. 2001). Throughout the entire Late Woodland period, intensive use of upland areas, most notably rockshelters throughout the Ohio River Valley, have been documented (Purtill et al. 2001; Snyder et al. 2002).

In contrast to earlier Middle Woodland Hopewell burial ceremonialism, Late Woodland mortuary practices are less elaborate in design although mound construction continues. Many of these mounds contain stone architecture such as rock cysts, slab-lined vaults, and pavements. For the first time, stone mounds are utilized in association with burials (Purtill et al. 2001). In many of the major drainage systems of southern Ohio, stone mounds appear directly associated with large nucleated sites. In addition, several middle Ohio River Valley sites have yielded human remains recovered from general midden areas

and not associated with formal cemetery zones (Shott et al. 1990). Mounds in the lower Ohio River Valley, located on blufftops overlooking rivers, often contain burials with grave goods, but no evidence would suggest differential burial based on status. Mortuary offerings are less exotic and suggest a reduction in long-distance trade items. Several artifacts do appear important in regional trade networks including "limestone and sandstone elbow pipes, narrow Chilton-style gorgets of bone and slate, late pentagonal pendants, and small sheets of mica" (Seeman and Dancey 2000).

Diagnostic projectile points of the period include the Lowe Flared Base, Jack's Reef Corner Notched, Jack's Reef Pentagonal, Raccoon Notched, and very late in the period, small triangular forms (Sieber et al. 1989). Wyandotte chert declined in use through the Late Woodland period as chert cobbles of glacial origin were used to produce the small points. Late Woodland ceramics include thin-walled, grog- or grit-tempered, cordmarked or paddle-impressed vessels that tend to represent simple utilitarian ware. The highly decorated vessels with incised motifs of the Middle Woodland period disappear.

Three Late Woodland cultural manifestations have been defined in southern Indiana within the lower Ohio River Valley—the Albee Complex of southwestern Indiana, the Newtown phase in southeastern Indiana, and poorly defined Late Woodland groups around the Falls of the Ohio (Sieber et al. 1989).

Late Woodland sites in southern Illinois are identified by the presence of thin-walled, well-made, cordmarked, grit- and/or grog-tempered ceramic vessels (Denny 1972; Maxwell 1951). Point types diagnostic of the period include the Lowe Flared Base point, the Mounds Stemless point, and small, corner-notched points, including the Jamestown point. The appearance of small triangular and side-notched projectile points sometime after A.D. 600 indicates the adoption of the bow and arrow. Late Woodland materials were recovered from the Rose Hotel in Hardin County, Illinois (Wagner and Butler 1999) and at Horseshoe Lake in Alexander County, Illinois, at the confluence of the Ohio, Mississippi, and Cache rivers (Koldehoff and Wagner 2002).

The Lewis focus, now referred to as the Lewis phase, was defined by Cole et al. (1951) to include Late Woodland materials in the lower Ohio River Valley in extreme southern Illinois. Lewis pottery displays some red filming and incised line decoration (Hargrave 1992) and are tempered with fine grit, crushed clay, or both. Vessel shapes are characterized by rounded bases and constricting rims. Surface treatment is characterized by punching or notching with dowels on the lip and cordmarking.

Winters (1967) suggests that Lewis materials are rarely found outside the lower Ohio River Valley in Massac and Pope counties. However, investigations at several of the so-called "stone forts" in the Shawnee Hills suggest that these specialized sites might sometimes be associated with the Lewis phase. This affiliation has been proposed for Hog Bluff (Brieschke 1972) and Cypress Citadel (Klein 1981). Lewis phase pottery sherds have also been recovered from rockshelters in the Shawnee Hills (Latham and Baer 1997; Wagner et al. 1992).

Toward the end of the Late Woodland in the lower Ohio River Valley, the Yankeetown phase appears in southwestern Indiana, southeastern Illinois, and northwestern Kentucky (Sieber et al. 1989) The Yankeetown phase represents the true transition between the earlier Woodland traditions and the developing Mississippian

tradition. Ceramic forms increase in diversity as bowls, pans, pottery trowels, human figurines, and ceramic discs appear. Typical decorations on vessels include incised or filleted lines with rectangular or curvilinear zoned motifs. Bar stamping also occurs (Redmond 1986; Kellar 1983). Yankeetown settlements appear as sizable sedentary farming villages and small hamlets scattered among the floodplains of larger streams. Small extraction camps occur both in the bottomlands and uplands. The location of the villages on prime soils, the appearance of large storage pits and chert hoes, and an increase in maize production, all point to a shift toward an agricultural economy. Investigations in the Carrier Mills area of Saline County, Illinois, have shown that Yankeetown components are present in the Saline River Valley (Jefferies 1987), as have excavations at the Great Salt Spring in Gallatin County, Illinois (Peithman 1953). The Duffy site (11G132), type site for the Duffy complex (now included in the Yankeetown phase), is located on the Wabash River in northeastern Gallatin County, Illinois, and Yankeetown potsherds have also been recovered from a few rockshelters in the eastern Shawnee Hills during Forest Service CR surveys (Moffat et al. 1985; Wagner et al. 1992).

In the upper Ohio River Valley, radiometric assays from Late Woodland, Late Prehistoric, and Protohistoric groups overlap significantly. Consequently, these groups are generally discussed together. There is a lack of Mississippian influenced cultures such as Fort Ancient in the upper Ohio River Valley (Weed 2004). Of all the prehistoric cultural periods in the upper Ohio River Valley the Late Woodland/Late Prehistoric/Protohistoric is the most thoroughly investigated (Weed 2004). Two phases are represented in this region of the valley during this period and they are the Whittlesey and Monongahela (Weed 2004). Of these two, the Monongahela phase is the major presence in Pennsylvania and West Virginia (Weed 2004). Generally, the settlement pattern for the Monongahela sites is one of large sites on the floodplains and smaller sites in the uplands. Village sites tend to have palisades with round to oval shaped houses arranged around an open plaza (Weed 2004). Shell tempered, cordmarked and plain pottery appears for the first time during the Late Woodland/Late Prehistoric/Protohistoric period.

It was during the Mississippian period that the prehistoric cultures in the Southeast and middle Mississippi River Valley reached their peak of sociopolitical complexity. The period is marked by the development of complex chiefly societies characterized by hereditary authority and social ranking. This period is best known for the large, fortified civic/ceremonial centers constructed along major rivers valleys. Large, earthen, substructure mounds were constructed on which the houses/temples of the elite were built. Extensive exchange routes were established along which exotic, nonlocal materials were widely exchanged. An agricultural economy became firmly established with maize, beans, squash, and pumpkin being grown to augment traditional hunting and gathering. Typifying the Mississippian period is shell-tempered pottery, small triangular projectiles, a wide diversity of ceramic forms, and square to rectangular houses (many with subterranean floors). Exotic, nonlocal cherts were widely exchanged, including Dover chert from Tennessee and Mill Creek chert from Union County, Illinois (Sieber et al. 1989).

Mississippian organization was based on a domestic economy with the household forming the basic economic unit of the Mississippian community. Settlements consisted of large, fortified towns containing mounds, unfortified villages, hamlets, and individual households (Muller 1986; Smith 1978). Small special purpose structures that possibly served as farming stations may have been attached to households (Finney 1993).

In the middle Ohio River Valley after A.D. 1000 the Fort Ancient complex is defined. Current research suggests that Fort Ancient developed out of the local Late Woodland cultures, although varying degrees of Mississippian influence and inter-regional migration (Purtill et al. 2001) have been forwarded. Within the Ohio River Valley, Fort Ancient extends from western West Virginia to southeastern Indiana. In Kentucky it is divided into three separate time spans: Osborne, Middle Fort Ancient, and the Madisonville Horizon.

Fort Ancient is characterized by large permanent villages located along major drainages on terrace and blufftop landforms. From A.D. 1000 to 1400, villages tend to be organized around a central plaza with concentricallly arranged rings of storage/refuse pits and houses. Burial mounds were not used extensively and by ca. A.D. 1250/1300 are not constructed at all (Cowan 1986, 1987; Purtill et al. 2001). Contexts for non-mound burials are varied and may occur around the central plaza, in cemeteries away from villages, or beneath house floors.

Fort Ancient pottery is characterized by an increase in the use of shell tempering through time (Purtill et al. 2001). Up to A.D. 1300, ceramic decorations show an increasing amount of decoration as designs such as curvilinear and rectinlinear guilloche designs become popular. Vessel shapes are restricted to elongated and gobular jar forms, although some pan forms have been documented. Projectile points are mostly thin, triangular forms that indicate the dominance of bow hunting (Purtill et al. 2001).

Subsistence during the Fort Ancient period became more heavily dependent on beans, maize, and squash, although evidence suggests that wild plant foods also remained an important part of the diet (Wheelersburg 1992; Purtill et al. 2001). Population increase occurred as a result of increased sedentism and a shift to a more intensive agricultural base. Settlement continued in stockaded villages, many on blufftop areas of floodplains. Although village sites have received the bulk of archaeological investigations, recent research has documented the existence of several small, seasonally occupied extractive/hunting camps (Brose and White 1983; Purtill 1999; Purtill et al. 2001).

Beginning around ca. A.D. 1400, Fort Ancient sites demonstrate a drastic reorganization of lifeways that differ from earlier periods. Archaeologists have termed this the Madisonville Horizon to reflect increased pan-regional interactions in artifact styles, including ceramic and lithic tools, with various groups within, and surrounding, the Fort Ancient culture area (Henderson 1992; Purtill et al. 2001). The traditional circular village pattern is replaced by roughly linear, poorly organized village plans (Cowan 1987). Evidence from the Driving Range site (33Ha586) in southwestern Ohio suggests that seasonal abandonment of summer villages for winter camps, referred to as the Miami-Potwatomi settlement system (Fitting and Cleland 1969), was being practiced for the first time in the Fort Ancient culture area (Purtill 1998, 1999; Purtill et al. 2001).

After A.D. 1400, a number of trends in artifact styles have been documented. Ceramic decorations become dramatically plain as curvilinear and rectilinear guilloche designs cease to be used in high frequencies (Cowan 1986, 1987). The incidence of ceramic salt pans occurs in high frequency for the first time (Purtill et al. 2001). Similar trends in ceramic styles have been observed in Kentucky (Henderson 1992) and West Virginia (Graybill 1981). Tool types that are argued to be diagnostic of the Madisonville

Horizon include bifacial, tear-drop end scrapers, bi-pointed knives, and carved bone pins (Cowan 1987; Henderson 1992).

There is evidence that some Late Woodland and Fort Ancient sites were occupied into the proto-historic period. The Madisonville site (33Ha14) in Hamilton County, Ohio, and the Morrison Village site in Ross County, Ohio, have yielded European trade goods suggesting occupation well into the seventeenth century (Drooker 1997). However, beginning in the mid-seventeenth century, aboriginal occupation of Ohio was disrupted when groups involved with the European fur trade in the Northeast began to expand the geographical range of their activity (Purtill et al. 2001).

Two coeval expressions of the Mississippian period existed in Indiana and the lower Ohio River Valley that represented different economic, political, and social adaptations. The Middle Mississippian culture is derived from influences from the southeast and involves the development of complex chiefly societies and the creation of one of the most complex prehistoric sociopolitical organizations to develop in North America. Middle Mississippian sites are limited to the southern half of the state with most sites occurring in southwestern Indiana. The Upper Mississippian is used to designate groups contemporaneous with, but outside, the Middle Mississippian cultural sphere. In essence these groups represent the "Mississippianization" of local Late Woodland groups (Sieber et al. 1989). This includes the Fort Ancient Aspect (Griffin 1943; Sharp and Turnbow 1987) centered in southeastern Indiana, southern Ohio, and northern Kentucky. Containing many Middle Mississippian attributes, the Fort Ancient sociopolitical organization never reached the complexity of settlements to the south. The Fort Ancient and Middle Mississippian cultures mixed in southwestern Indiana so that aspects of both traditions can be found in the region. The Oliver phase and the Vincennes culture are represented by this mixing (Dorwin 1971; Barth 1982; McCullough 1991, Redmond 1991; Redmond and McCllough 1993).

In southern Indiana the Upper Mississippian period is represented by the Angel (A.D. 1050–1450) and Caborn-Welborn phases (A.D. 1400–1600) (Sieber et al. 1989). The Angel phase is dominated by the Angel site in Vanderburgh County on the Ohio River. It encompasses more than 100 ac. and consists of residential areas, plazas, mortuary mounds, and elite zones associated with substructure mounds (Black 1967). The Angel phase has a diverse ceramic assemblage containing elaborate, well-made vessels. Angel and some surrounding villages were fortified with a surrounding stockade that may suggest conflicts, perhaps intermittent, between polities of the Mississippian period.

The later Caborn-Welborn phase is centered on the confluence of the Wabash River and the Ohio River. This regional variant is restricted in area, occurring only along a 50 km stretch of the lower Wabash River Valley. It is not known whether the Caborn-Welborn represents the breakdown of the Mississippian tradition or, more likely, a remnant of the Vincennes culture (Winters 1967) which was centered at the mouth of the Embarrass River. Caborn-Welborn populations were dispersed into large and small villages, individual homesteads, and hamlets (Sieber et al. 1989). Fortified villages or substructure mounds have not been found associated with these sites. European trade goods, glass beads, and brass items have been found in context with Caborn-Welborn sites. Whether direct contact took place with Europeans or whether these items arrived through exchange with neighboring native groups is not presently known (Sieber et al. 1989).

An important site in the southern Illinois region is the Kinkaid Mounds. Located in the Black Bottom area of the Ohio River, this site is composed of a number of hamlets located around a cluster of mounds, with evidence of a palisade construction along at least the north side of the site (Muller 1978). Additional areas of occupation and/or utilization have been identified in various portions of the Black Bottom area. While occupation of the area may have ranged from A.D. 900–1500+, recently obtained radiocarbon dates indicate that Mississippian exploitation of the locality likely climaxed during the 1200s (Muller 1978). Studies attempting to model Mississippian settlement patterns in the Black Bottom locality have met with some success (Butler 1977; Lafferty 1976; Muller 1978), while efforts to understand, or even identify, settlement patterning in the adjacent upland areas have proven more difficult. Recent excavations at Kincaid Mounds by Southern Illinois University-Carbondale took place for a proposed parking lot (Butler and Welch 2003). This investigation showed a Mississippian low platform mound definitely was built on the ridge terminus, although the size and ultimate height of the construction are uncertain. It has been largely leveled due to deflation and erosion under long-term farming. Outside of the immediate confines of the mound construction there is a layer of heavy Mississippian refuse with associated habitation features on the south slope of the ridge. Similar deposits on the north slope of the ridge with embedded houses and other features were recorded by earlier investigations. How much of this is the accumulation of refuse in a habitation area, and how much of it is mound fill (or displaced mound fill) is not certain (Butler and Welch 2003). These midden-like deposits have a high refuse content that includes considerable faunal material. It is evident that from the mid-slope south toward the road, the Mississippian and even some Baumer deposits have been progressively truncated by the earthmoving associated with the 1953 road work.

The Rose Hotel in Hardin County, Illinois, also has a Mississippian presence (Wagner and Butler 1998). Occasional finds of shell-tempered pottery or triangular projectile points also have been made in rockshelters located in the eastern Shawnee Hills (McCorvie 1991; Moffat et al. 1985; Penny 1983). These finds suggest occasional use of the Shawnee Hills by Mississippian peoples. There is also some evidence of Mississippian occupation in the Saline River Valley to the north of the Shawnee Hills. Several Mississippian farmsteads were excavated during the Carrier Mills project. The Saline Springs in Gallatin County were extensively utilized during the Mississippian period (May 1984).

Most petroglyphs in the Ohio River Valley are likely late prehistoric in origin, however, Woodland and Archaic petroglyphs sites are known. Mississippian period petroglyphs are generally situated in relatively inaccessible locations, possibly indicating a setting for ceremonial activity. The petroglyphs include anthropomorphic figures, foot/hand prints, various animals-in particular bird designs, bi-lobed arrow designs, and assorted circles and crosses. All of these designs are considered typical of the Southeastern Ceremonial Complex, which is a wide-spread complex of specific motifs and ceremonial objects associated with Mississippian period religion and ritual (Wagner et al. 1990). Such sites are documented from West Virginia to Illinois within the Ohio River Valley. Additional information on Ohio River Valley petroglyphs can be found in the following: Braley 1993; Cochran and Wepler 1994; Collins 1874; Coy 1991, 1995; Coy et al. 1997; Fowler 1977; Mallery 1893; Murphy 1978; Swauger 1961, 1968, 1974, 1984; and Wellman 1979.

12.7.2 Historic Cultural Resources

Archaeologists have worked to reconstruct the cultural and historical threads that knit together the native cultures of the Late Prehistoric and early historic periods in the Ohio River Valley with the more familiar named tribes associated with the historic contact period. As the above text indicates, the Late Prehistoric peoples of the Fort Ancient culture, for example, were once numerous in the Ohio River Valley. However, the rare historical and even more limited archaeological data for the immediately succeeding Protohistoric period, just prior to the time of the first contacts between Native Americans and Europeans; indicate that by A.D. 1650-1700 few Native Americans permanently resided in the upper Ohio River Valley. In fact, early European explorers and Euro-American settlers coming to the Ohio River Valley in the mid to late eighteenth century found few Native Americans who had been long-time residents of the region. Only small hunting camps and a few villages were found. Hunting parties ranged throughout the area as wild game abounded. Near the headwaters of the upper Ohio River at the confluence of the Monongahela and Allegheny rivers, early European surveyors, traders, and settlers encountered members of the Seneca, Delaware, and Shawnee tribes who used the area during hunting expeditions. There were, however, indications of earlier, more extensive human occupations from the periods described above including stone implements, pottery, human burials, and well-worn trails. The most dramatic signs of earlier permanent human occupation were the large earthen mounds and mound groups, which often occurred at or near the confluence of tributaries with the Ohio River.

The archaeological literature suggests that the lower Ohio River Valley was sparsely settled after the decline of the Mississippian civilization around A.D. 1500. There is little evidence of settlements of any size or duration of occupation during the period of initial contact with white settlers and explorers. A number of tribes used the area for hunting and fishing, following the rivers and their tributaries as well as the buffalo traces that crossed the region. Along the lower Ohio River these tribes included the Creeks, Chickasaw, Choctaw, Shawnee, Yuchi, and Cherokee.

As a result of the initial exposure to Europeans and diseases from which the native peoples had no natural immunity, all these tribes suffered from various contagious diseases during the eighteenth century. The severe and sudden population decline resulting from these diseases disrupted their traditional way of life and reduced their ability to resist incursions by European settlers (Carlisle and Mulligan, 2001). In the *New History of Kentucky,* it is estimated that by 1750 there were no more than 3,000 to 4,000 Shawnee in all of Kentucky (Klotter and Harrison 1997).

Islands comprising the upper Ohio River Islands National Wildlife Refuge figure prominently in the history of the river based on early accounts by explorers of contemporary Indian groups, survey expeditions by George Washington, the settling of the Ohio River by pioneers and traders, strategic battles during the Civil War, and river development for navigation and industry. Many islands were large enough to be permanently settled or industrialized. Neville Island, about five miles downstream from Pittsburgh, became an active industrial site during the late 1800s. In 1798, a large Palladian mansion, in the style of Mount Vernon, was built on Blennerhassett Island near Parkersburg, West Virginia. Harman Blennerhassett, the builder of the mansion, later was accused of conspiracy with Aaron Burr. The 7,000-square foot mansion burned in 1811,

but has since been reconstructed as the centerpiece of Blennerhassett Island State Park, a distinctive cultural resource in West Virginia (USFWS 2000).

As early as 1780, a military party noted the large mounds at the mouth of the Muskingum River, at the site of the future Marietta, Ohio (Carlisle and Mulligan 2001). In fact, these mounds were incorporated into the new plans of the town when the construction of Marietta began in 1787-1788. Prehistoric mounds and mound complexes also once stood at the location of many other Ohio cities including Circleville, Chillicothe, and Cincinnati, though most were ploughed away in the early days of settlement (Jakle 1977). Extant Ohio River mounds listed by the U.S. National Park Service as National Historic Landmarks include Grave Creek Mound (Moundsville, West Virginia), which dates to 500 B.C. representing the Adena culture and Angel Mounds (near Evansville, Indiana), which date to A.D. 1000-1600 representing the northeastern most extension of the Mississippian culture.

Beginning in the eighteenth century, various explanations to account for Native American artifacts, trails, and earthen mounds were developed and debated. The architectural complexity and sophistication of the mounds and the numerous abandoned sites across the landscape provided a sharp contrast to the simpler, then current Native American condition, which was interpreted to be the result of a cultural disjunction. Early explorers and settlers were unaware that the comparatively simple bands of migratory native hunters and horticulturists of their own day were the products of more than a century of cultural upheaval, dissolution, and widespread geographical relocation. This cultural turmoil beyond the Appalachian Mountains had been precipitated by the development of sustained European settlement on the eastern seaboard beginning in 1607 and by related socio-political changes within other Native American cultures (Carlisle and Mulligan 2001).

French and British fur traders frequented the Ohio River Valley early in the eighteenth century, but permanent occupation by Europeans did not begin until the mid-eighteenth century when a few isolated military outposts were established in the valley. These outposts included the French Fort Duquesne (1754) and, and a few years later, the British Fort Pitt (1758) at the Forks of the Ohio, the site of present day Point Park in Pittsburgh. Far down river, near the confluence of the Ohio with the Mississippi River, the French built Fort Massac in 1757 near present-day Metropolis, Illinois, later occupied by both the British and Americans. Three major factors, however, delayed extensive settlement in the Ohio River Valley during much of the eighteenth century: (1) larger ongoing European political struggles; (2) nearly constant hostility between settlers and (3) Native Americans; and the American colonists' struggle for independence from Great Britain. Several cities along the lower and middle Ohio River were founded in the late 1700s including Louisville in 1779 at the Falls of the Ohio, the most significant break in navigation on the river, East Liverpool (1797); Steubenville (1798); Marietta (1788); and Cincinnati (1788) – all in Ohio; Wheeling, West Virginia, had been settled somewhat earlier (1770s) while the communities of Parkersburg and Huntington, West Virginia, both remained small until well into the nineteenth century. Pittsburgh was founded in 1758 at the headwaters of the Ohio River.

Following the Treaty of Paris (1783), formally ending the American Revolution, the Land Ordinance of 1785 provided for the administration and subdivision of land in the Northwest Territory. The new territory consisted of land north of the Ohio River, west of

Pennsylvania and east of the Mississippi, including all of present-day Ohio, Indiana, and Illinois and parts of Michigan and Wisconsin. East Liverpool, Ohio, on the Ohio-Pennsylvania border, was the point from which the rectangular-grid land survey system was developed under the ordinance. The search for good agricultural land was the major impetus to westward migration and settlement of the Northwest Territory (USFWS 2000). Many settlers to Kentucky, Indiana, and Illinois came overland from the southeast through the Cumberland Gap.

The Battle of Fallen Timbers (1794) near Maumee, Ohio, and the subsequent Treaty of Greenville were key events leading to the cessation of hostilities between settlers and Native Americans in the upper Ohio River Valley and opened the way for more extensive settlement. Within the lower Ohio River Valley Cantonment, Wilkinson in Pulaski County, Illinois, was established during 1801-1802 and was archaeologically located by SIU-C recently (Wagner 2003a). Some 1,000 men were stationed there out of a total of 3,500 for the entire U.S. Army. At the time, it was the largest post in the United States. Several of the men stationed there went on the Lewis and Clark expedition (Wagner 2003a). A cemetery with approximately 80 burials of soldiers who died of malaria and dysentery has never been located at the location of the cantonment. Another major event that opened the way for the development of settlements in the lower Ohio River Valley was William Henry Harrison's victory over the Shawnee at the Battle of Tippecanoe in Northern Indiana in 1811. The event was a turning point in British-inspired Indian problems since following that battle the confederation of the eastern tribes disintegrated.

Additional lower Ohio River Valley communities were founded during the same era near the confluence of significant tributaries, including the Kentucky communities of Owensboro (late 1790s), Henderson (1797), and Paducah (1795). The second largest city on the lower Ohio River for most of its history, Evansville, Indiana, was not founded until 1812. The eastern banks of the Ohio River became the departure point for many settlers down the Ohio River and into the territory to the west. Flatboats were an important mode of transportation for settlers heading to the Northwest Territory from Pittsburgh, Wheeling, and other ports in the upper Ohio River.

Flatboats were sturdily constructed, flat-bottomed craft about 50 feet long, typically only capable of traveling downriver. Ohio River Valley farmers and merchants constructed flat-bottomed vessels known as "flatboats" for over 125 years from the 1770s to 1900 (Wagner 2003b). Prior to the Civil War, thousands of these boats transported people, animals, farm produce, and manufactured goods down the Ohio River as far south as New Orleans (Wagner 2003b). There the vessels were broken up and sold for their lumber with the crews walking or riding steamboats back home. No intact examples of this vessel type are known to exist today. In 2000 local residents discovered the first physical remains of a flatboat yet found along the Ohio River shoreline a few miles above Cairo, Illinois. This vessel, called the America, was investigated by SIU-C. It is an estimated 45 ft. long x 12 ft. wide flatboat dating to ca. 1812-1820 (Wagner 2003b).

The invention of the steamboat in the early nineteenth century was highly significant in transforming the settlement of the entire Ohio River Valley because steamboats were capable of two-way transportation. The 1815 voyage of the steamboat *Enterprise* from New Orleans to Louisville in 25 days made the potential for steamboats clear (Carlisle and Mulligan 2001). Share (1982) reinforces the significance of steamboats for the Ohio River Valley in this passage:

By slashing distance and travel time, steam navigation transformed the Ohio Valley into a settled and cultivated region in a single generation. A northward and eastward movement of goods came to supplement downriver commerce, as steamboats and a series of canals constructed in the 1820s and 1830s connected the Ohio Valley to the Great Lakes and the Atlantic seaboard.

The two-way transport of agricultural products and industrial supplies greatly contributed to the economic growth of the region. Louisville became pivotal for the rapidly expanding trade between Pittsburgh and New Orleans, and all points in between, because the Falls of the Ohio remained an obstacle to navigation until a canal around the falls was completed in 1833. As river traffic increased, pirates preyed upon travelers and slow-moving steamboats. Cave-in-Rock, a 55-ft. wide limestone cave visible from the Ohio River in Hardin County, Illinois, was notorious as a lair of river pirates and criminals from the late 1790s until the mid-1830s. It is now a state park. Pirates also occupied some of the numerous islands located within the river.

The development of communities and trade during the early steamboat era transformed the Ohio River Valley within a few decades. Consequently, by the middle of the nineteenth century, fine homes and public buildings were erected in communities all along the Ohio River.

12.7.3 National Historic Landmarks

Many nineteenth century buildings have been preserved in historic districts within the Ohio River Valley. Several of the finest surviving residences are on the list of National Historic Landmarks (NHL), which are considered to possess exceptional value or quality in illustrating or interpreting the heritage of the United States. The Industrial Revolution affected the Ohio Valley and left outstanding architectural examples that represent nineteenth century efforts to include symbolic and monumental functions in industrial architecture. Two such NHL, visible from the river, are: the Louisville Water Company Pumping Station, constructed from 1858-1860 in the Classical Revival style with an engine room in the form of a temple and a 169 ft.-tall standpipe tower that imitates Roman columns; and the Cannelton Cotton Mills, begun in 1849 in Cannelton, Indiana, one of the most impressive pre-Civil War mills in the Midwest, topped by 100-ft. sandstone Italianate towers.

The nineteenth century also witnessed the construction of two suspension bridges over the Ohio River that continue to be important as both historic and active transportation resources. The Wheeling Suspension bridge, begun in 1849, was the first bridge to cross the Ohio River, allowing the National Road (which became U.S. 40) to move forward. With a span of 1,010 feet, it was the longest suspension bridge in the world upon completion. The NHL program describes the bridge as possibly the most significant extant ante-bellum engineering structure of the nation and adds that its construction established American leadership in the building of suspension bridges (http://tps.cr.nps.gov/nhl). An even longer suspension bridge was completed between Covington, Kentucky, and Cincinnati, Ohio, in 1867. The bridge is now named the John A. Roebling Bridge, after its designer. With its 1,057-ft. span, vertical suspenders and diagonal stays, the bridge became Roebling's prototype for the Brooklyn Bridge (1883).

Throughout the nineteenth century and during the Civil War, the Ohio River was an important geographic and cultural boundary between slavery and free labor. Bigham (1998) notes the legacy of that boundary continued to be felt many decades after the Civil War. With its islands, fords and lower water level, the pre-impounded Ohio River offered opportunities for slaves to escape to freedom. Many places on both sides of the Ohio River served as stations on the Underground Railroad. Two of the better known sites that are listed as NHLs are in the small river town of Ripley, Ohio (Brown County):

- the Rankin House, considered one of the first stations on the Underground Railroad and the place where Harriet Beecher Stowe heard the escaping slave's story which became the basis for *Uncle Tom's Cabin*; and
- the Parker House, where former slave, John Parker, lived and operated a foundry while rescuing slaves along the Ohio River.

Upriver in the old community of Maysville, Mason County, Kentucky, the National Underground Railroad Museum preserves and displays artifacts that document activities of the Underground Railroad. Interest in the Underground Railroad is further documented at the National Underground Railroad Freedom Center on the Cincinnati riverfront at the foot of the Roebling Bridge. The 160,000 square-foot-center documents the history of the Underground Railroad and encourages Americans to ensure freedom in the twenty-first century. Among the CR from the Ohio River during the twentieth century are three floating NHLs that represent different aspects of life on the river:

- the *W.P. Snyder, Jr.*, originally built as a towboat in 1918, is the last intact steam-powered, stern-wheeled towboat in the U.S. It is currently a floating exhibit of the Ohio River Museum in Marietta, Ohio
- the *Majestic*, built in 1923, is one of only two surviving American showboats. Earlier in its history, the Majestic carried theater productions to river towns along the Ohio and Kanawha rivers. Moored at the Cincinnati Public Landing, it still offers theatrical productions during warmer months; and
- the *Mayor Andrew Broaddus*, completed in 1929, is the only floating lifesaving station in the U.S. The *Broaddus* is the third such station located on the Louisville waterfront. It now serves as the wharfboat for another historic vessel, the *Belle of Louisville.*

During the twentieth century, high-lift dams constructed along the length of the Ohio River transformed the river. The decades-long construction process will be completed when the most downstream project, Olmstead Lock and Dam (replacing Dams 52 and 53), is completed in 2011. By raising the level of the river, high-lift dams have inundated fords, portions of islands and mouths of tributaries that were above water during prehistoric and early historic times (USFWS 2000). The older locks and dams on the Ohio River are of sufficient age to now be evaluated for eligibility for placement in the NRHP, thus representing a new generation of CR along the ever-changing Ohio River.

12.7.4 National Register of Historic Places

The NRHP was established by the NHPA of 1966 (**Table 12-2**). Prior to that date, no official national list of CR worthy of preservation existed. The NRHP and state CR registries list hundreds of CR found to be significant to the history of the country. **Figure**

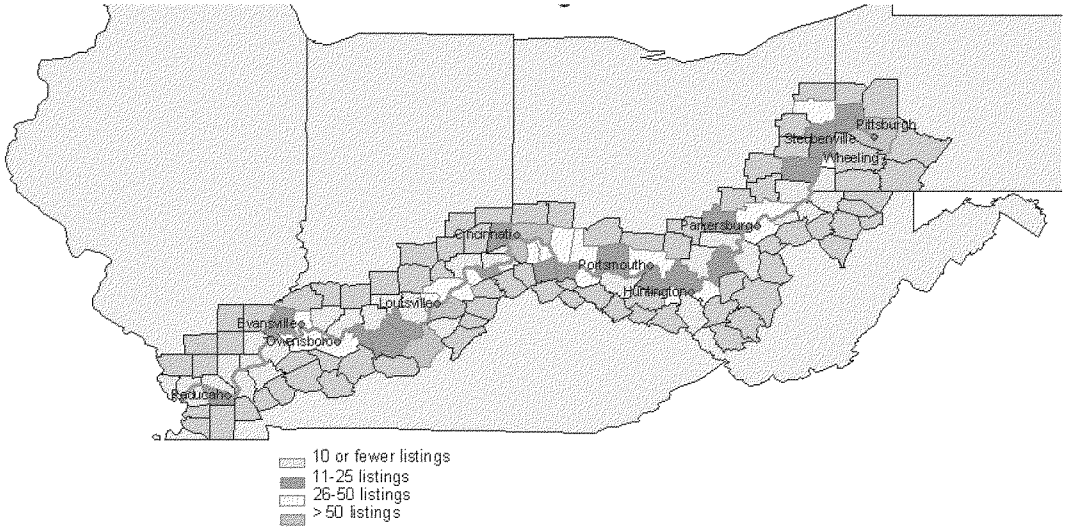
12-1 illustrates the number of listings on the NRHP by county along the Ohio River. Listings ranged from only one in a rural county of West Virginia to approximately 500 listings in the Louisville region, Jefferson County, Kentucky. Not surprisingly, the highest number of listings on the NRHP is associated with the most populous areas. Conversely, **Figure 12-1** shows that the least populous counties, such as the six counties along the Ohio River in Illinois, have fewer than 10 listings each. According to NRHP coordinators contacted for the states along the Ohio River, numbers of listings also reflect local and state levels of interest, effort, and funding for historic preservation.

The annual number of new listings has remained relatively stable in the past decade in Pennsylvania, Ohio, Indiana, and Illinois and is predicted to remain at a similar level in the coming decade. Kentucky, in contrast, has observed a decline in numbers, related in part, to a different listing process used during the 1970s and 1980s. Regarding the future of NRHP listings in Ohio River counties, some historic preservationists believe the more transitory nature of structures currently being built will translate into fewer structures being eligible for listing by the mid-twenty-first century. A contrasting view holds that appreciation is growing for historic structures, in general, while new specific areas of preservation (e.g., vernacular architecture) are emerging.

Included on the NRHP are historic districts. The NHPA defines a historic district as "a geographically defined area, urban or rural, possessing a significant concentration, linkage or continuity of sites, buildings, structures or objects linked by past events or aesthetically by plan or physical development. A district may also comprise individual elements separated geographically, but linked by association or history." Such historic districts have been designated in both small communities and large cities along the Ohio River. The metropolitan counties associated with Pittsburgh, Cincinnati, and Louisville have dozens of listed historic districts while the smaller cities of Steubenville, Ohio (Columbiana County), Wheeling, West Virginia (Ohio County), Parkersburg, West Virginia (Wood County), and Evansville, Indiana (Vanderburgh County) each have five to 10 historic districts. Other smaller communities and counties that have listed historic districts include Beaver, Pennsylvania (Beaver County); Belmont County, Ohio (near Wheeling); Sistersville, West Virginia (Tyler County); Marietta, Ohio (Washington County); Huntington, West Virginia (Cabell County); Aurora, Indiana (Dearborn County); New Albany, Indiana (Floyd County); Henderson County, Kentucky (Henderson County); and Paducah, Kentucky (McCracken County). Downtown Madison, Indiana (Jefferson County) is the largest historic district along the Ohio River, encompassing over 1,000 nineteenth century structures.

Like historic districts, archaeological districts encompass areas where significant numbers of archaeological resources are concentrated. Archaeological districts are rarer than historic districts and are not specifically defined in the NHPA. An archaeological district essentially is a geographical cluster of archaeological sites that may or may not be linked by a common culture. The distribution of archaeological districts is uneven state-by-state and may be more reflective of state policies or the scale of a given project. Within the ORMSS study area, archaeological districts are listed on the NRHP for Greenup County, Kentucky and Hamilton County, Ohio.

FIGURE12-1
National Register of Historic Places Listings for Counties Along the Ohio River



12.7.5 Historic Navigation Structures

Section 110 of the NHPA requires federal agencies to assume responsibility for preservation of historic properties owned or controlled by them and to locate, inventory, and nominate all properties that qualify for the NRHP. Consequently, many of the locks, dams, buildings, and equipment originally built by the Corps on the Ohio River are themselves considered to be CR. As modern engineering and technology are fast replacing many early engineering designs, some early structures are deemed worthy of preservation or documentation for future generations (http://www.lpr.usace.army.mil/lmon/cult_resources.htm).

During 1999, the Corps evaluated 69 facilities associated with the navigational system along the Ohio River for potential inclusion in the NRHP (Hampton et al. 2003). Of the 69 facilities, seven that are active were determined eligible for the NRHP, while 31 that are inactive were determined to be eligible. The remaining facilities were determined to be ineligible for the NRHP.

The historic engineering evaluation in the Ohio River Context Study (McVarnish 2001) described the Ohio River navigation system as a "living laboratory of twentieth century lock and dam technology" and concluded that it clearly meets Criterion C of the NRHP, which states that structures that embody the distinctive characteristics of a type, period, or method of construction may be eligible. Because of its extensiveness and complexity, the Ohio River Navigation System pioneered the evolution of several significant areas of engineering, including:

- lock filling and emptying technology
- cofferdam technology and
- power generation in navigation complexes in the United States.

Other important engineering achievements on the Ohio River system include:

- movable Chanoine wicket navigable passes, still in place at Dams 52 and 53 and soon to be superseded by Olmsted Dam, which will include a modern, improved version of the navigable pass
- the first use of steel wall armor to protect concrete lock walls from the impact of vessels
- construction of the largest roller gates (125.5') in the U.S. at Gallipolis Dam and
- first use of a Sidney gate (with moving or sliding trunnion pins) in the back channel dam at Emsworth.

12.8 INTERACTIONS WITH OTHER VECS

CR are associated to varying degrees with several other VECs, but appear to be most closely related to those VECs associated with human communities, including socioeconomics, land use, transportation, and recreation. The most significant interactions and potentially adverse impacts to CR occur because of land use changes in the floodplain, which in turn are driven by socioeconomics. River transportation and traffic, also closely linked to socioeconomics, appear to directly affect CR primarily through bank erosion with

its attendant resource loss and to indirectly affect CR through the development of marinas, terminals, and multimodal sites that rely on river commerce.

Recreation is becoming increasingly important as cities and towns once again consider their riverfronts as community assets. Riverfront recreation areas have a mixed effect on CR. Land disturbance with potential damage or destruction of CR is somewhat counterbalanced by the enhanced knowledge and educational opportunities afforded by CR surveys undertaken during riverfront development.

A medium level of interaction occurs between CR and floodplain hydrology and terrestrial resources. As floodplain hydrology and terrestrial resources are modified by land use changes, CR also can become vulnerable to inundation, burial, or destruction.

12.9 RELEVANT ACTIONS AFFECTING CULTURAL RESOURCES

Of 87 actions included in the RFFA matrix, 23 actions were ranked "high importance," 17 actions were ranked "medium importance," and the remaining 47 actions were ranked "low importance." **Table 12-4** lists all actions ranked high or medium, indicates if the action is generally beneficial (+) or detrimental (-), and lists the effects of the action according to the following key:

I = causes inundation
C = causes covering or burial
D = disturbs soils resulting in CR damage or destruction
A/C = changes aesthetics or context
U = impacts potential underwater CR
BE = causes bank erosion
RP = resource protection/preservation
O = other, including acid rain, floods, and other climatic events

TABLE 12-4
RFFAs Ranked High or Medium for Cultural Resources

RFFA	Net Effect	Types of Effects
Actions of High Importance		
Lock extensions/new locks/replacement/rehabilitation	-	C, D, A/C
Lock and dam operation and maintenance	-	I
Dam replacement and rehabilitation	-	I, C, D, A/C
Levees/floodwalls	-	C, D
Dry dams/other projects off mainstem	+/-	RP, I
Nonstructural flood damage reduction measures	+/-	RP
Corps recreation facilities – Construction and O&M	+/-	C, D
Port development (Sec. 107) and maintenance dredging	-	U, C, D, I
Fleeting areas/barge storage	-	BE, U, C, D
Terminals	-	U, C, D, A/C
Multi-modal sites	-	U, C, D, A/C
Instream sand and gravel mining	-	U, C, D, A/C

RFFA	Net Effect	Types of Effects
Floodplain sand and gravel mining	-	C, D, A/C
Limestone aggregates mining	-	C, D, A/C
Non-Corps recreation facilities – Construction and O&M	+/-	C, D
Residential floodplain development	-	C, D, A/C
Commercial floodplain development	-	C, D, A/C
Industrial floodplain development	-	C, D, A/C
Private recreational sites, including campgrounds, docks and seasonal trailer parks	-	C, D
Casinos	-	C, D, A/C, RP
Floods	+/-	O, RP
Earthquakes	-	C, D, A/C
COE permitting programs	+/-	C, D, A/C, RP
Actions of Medium Importance		
Channel dredging/dredged material disposal	-	U, C
Channel modifications	+/-	RP, D
Modification of Corps structures for environmental improvements (sec. 1135)	-	I, D
Environmental restoration of aquatic ecosystems (Sec.206)	+/_	RP, D
ERP projects – 5 categories	+/-	RP, D
Coal utilities	-	C, D, A/C, O
Other coal industries	-	C, D, A/C, O
Hydropower on dams	-/+	C, D, RP
Bridges	-	C, D, A/C
Utility crossings	-	A/C
Industrial crossings	-	A/C
Marina development and operation	-	U, C, D, A/C
Silviculture	-	D
Agriculture	-	D
Trail/bikeway development	+/-	RP, C, D
Severe storms	-	O
Wetland mitigation banking	-	D

The following discussion focuses on RFFAs ranked high or medium in the CR RFFA matrix. RFFAs are grouped according to their primary effects, but it should be understood that most actions have multiple interrelated environmental effects.

12.9.1 Actions Causing Inundation

Actions that cause long-term flooding may damage, wash away, or inundate CR, making them off limits to future analysis or recovery. Continued lock and dam operation and maintenance is an RFFA of high importance that causes long-term inundation along the length of the Ohio River. Other RFFAs, aimed at protecting human safety, may have similar effects at specific locations. For example, from a CR perspective, nonstructural

flood damage reduction measures, such as relocation of housing from the floodplain, may result in loss of significant architectural structures or neighborhoods. Dry dams or other off main stem projects aimed at flood protection downstream similarly may result in the loss of CR at the off-main stem sites where flood damage reduction projects actually occur. On the positive side, the Section 106 NHPA requirement for federal projects to consider CR may result in the recovery and curation of historic or prehistoric artifacts that may have otherwise remained unknown.

Activities that produce localized changes in hydrology also cause damage or loss of CR through inundation. Such activities include wetland restoration during modification of Corps structures for environmental improvements and floodplain sand and gravel mining.

12.9.2 Actions Resulting in Damage or Destruction of Underwater Cultural Resources

Because CR associated with the streambed of the pre-impoundment Ohio River are largely unknown, it is possible that activities that alter or remove bottom substrates may result in damage or destruction to underwater CR, including prehistoric artifacts. Channel maintenance dredging and in-stream sand and gravel mining both directly remove bottom substrates and inadvertently any CR associated with them. Further, land disposal of dredged materials and land-based activities related to in-stream mining can bury CR on unsurveyed disposal or processing sites. Likewise, port development and maintenance dredging can potentially affect both in-stream and land-based CR.

Terminals and multimodal facilities also typically involve dredging during their development and operation, with potential attendant damage to unknown CR. Associated land-based activities can result in damage or destruction of CR caused not only by construction of the terminals or multimodal facilities themselves, but also compounded by land transportation facilities, including new roads and rail spurs that service them.

12.9.3 Actions Causing Damage or Destruction through Burial or Land Disturbance

Our incomplete knowledge of CR along the Ohio River, as well as, their lack of visibility, makes CR near the land surface particularly vulnerable. **Table 12-4** lists the broad range of important RFFAs that can damage or destroy CR through covering, burial, or land disturbance. Any type of construction activity that involves establishing laydown yards for materials and equipment, clearing, grading, disposal areas, or excavation has the potential to damage, destroy, or bury historic and prehistoric CR. Such construction-related RFFAs include lock extensions/rehabilitation, dam replacements/rehabilitation, levees, all types of floodplain development (residential, commercial and industrial), as well as energy-related and river commerce development and operation. To a lesser extent, even Environmental Restoration Projects, designed to restore natural resources, may have negative construction effects on unknown CR.

Construction of recreation facilities, including Corps and non-Corps parks and playfields, trails/bikeways, and private seasonal trailer parks and campgrounds similarly can have negative impacts on CR. Further, human intrusion or overuse may lead to degradation of CR that may be incorporated into recreation areas. On the other hand,

recreation facilities sometimes benefit CR by affording opportunities to heighten public awareness through interpretive exhibits and programs.

Agriculture and silviculture, although not construction activities, are ranked as having a medium impact on CR because of plowing, planting, and possible intrusion of root systems on buried CR. Earthquakes, though infrequent, are also ranked medium for their potential to causing cracking, destruction, or burial of resources through land disturbance.

12.9.4 Actions Causing Bank Erosion

Erosion occurring through wave and water action can cause loss when river banks slough and associated CR are damaged or disappear. Prehistoric and historic artifacts are vulnerable to loss through erosion when channel modifications alter currents and affect riverbanks and islands. Fleeting areas/barge storage was ranked of high importance on **Table 12-4** primarily because of the potential for bank erosion to affect CR. Barge queuing, although rated low in the CR matrix, is another RFFA that may cause bank sloughing and loss of CR.

12.9.5 Actions that Alter Aesthetics or Context

As mentioned under Indicators of Environmental Sustainability (ES), CR not only are evaluated by their individual condition but also by the stability or integrity of their context. Context, as pertinent to this discussion, involves several factors including auditory, visual and atmospheric encroachment, and overuse. Because integrity of context of CR is somewhat subjective, changes in surrounding land use that compromise or obliterate the contextual significance of an historic structure may be interpreted negatively. **Table 12-4** indicates that bridges, utility crossings, and industrial crossings are examples of RFFAs considered to have important aesthetic/context impacts on CR.

12.9.6 Other Actions

Included in this section are RFFAs that do not readily fit into the previous categories, such as certain natural climatic events. Floods (ranked high) may directly damage CR through floodwaters, erosion, or sedimentation. Floods also may expose previously unknown resources, potentially contributing to our knowledge of CR within the Ohio River Valley. Severe storms (ranked medium) can damage or destroy CR through heavy winds, lightening strikes, tree uprooting, and water damage.

Another weather-related RFFA with singular impacts is related to power generating facilities and other coal utilities located along the Ohio River. The emissions of such facilities have been linked to acid rain and resultant damage to CR located northeast of the Ohio River Valley, but within the Ohio River Valley air shed.

12.10 CUMULATIVE EFFECTS AND ENVIRONMENTAL SUSTAINABILITY

One of the seven environmental operating principles of the Corps is to strive to achieve ES. ES is defined as a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design,

construction, operation, and maintenance to improve the quality of life for present and future generations. Accordingly, ES represents an "ultimate test" whereby the significance of cumulative effects can be evaluated. This test is applicable for programmatic impact studies wherein a broad, "high altitude" perspective is utilized. An Analysis of Environmental Sustainability (AES) has been and is being used in several other programmatic studies by the Corps. In fact, AES is perceived as an emerging integrator for impact studies in the United States and internationally, particularly in Europe.

The AES approach used herein consisted of three steps: (1) identification of "common effects" on CR from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix; (2) selection of indicators for ES of CR, and their grouping, as appropriate; and (3) consideration of the "connections" between common effects and indicator groups. The output of the AES consists of a qualitative (descriptive) discussion of the "connections," with the discussion derived from some quantitative data and scientific information, along with professional judgment. The final output addresses the following questions – what is the current ES for CR, and is it expected to improve or decline in the future? Three categories of ES are used to answer these questions. The following specific definitions were used:

- Not sustainable – the composite conditions for the selected indicators of ES for CR do not reflect conditions that would sustain CR in the Ohio River mainstem study area
- Marginally sustainable – the composite conditions for the selected indicators of ES for CR are "borderline" for ES, and there are uncertainties regarding specific quantitative measures for ES
- Sustainable – the composite conditions for the selected indicators of ES for CR are good and exceed regulatory thresholds or other pertinent measures.

Several common effects of multiple actions have been previously discussed in the section entitled "Relevant Actions Affecting Cultural Resources"; they include actions causing inundation, actions causing damage or loss of underwater CR, actions causing burial or land disturbance, actions causing bank erosion, and actions that alter aesthetics or context.

Six indicators of ES were identified earlier in the section entitled "Indicators of Environmental Sustainability," and relevant information on them has been presented in the section entitled "Past to Current Baseline Conditions."

12.11 CONCLUSIONS

In summary, the ES of CR associated with the Ohio River mainstem, as illustrated in **Figure 12-2**, can be depicted and characterized as follows:

- In the period from 1920 and continuing until passage of the National Historic Preservation Act of 1966 and other preservation acts later in the twentieth century, limited measures were in place to preserve and protect CR; most resources remained unsurveyed. Widespread razing of potentially historic structures during this time is viewed by some SHPO

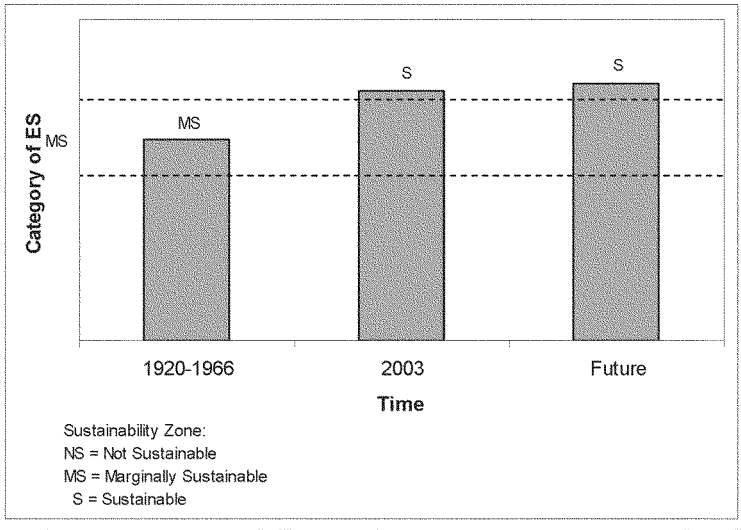
professionals as having contributed to a decline such that CR may overall have been at the "marginally sustainable" level.

- The implementation of CR legislation, including creation of the NRHP and establishment of the SHPO, has heightened awareness of the need to preserve historic structures in communities along the Ohio River. Simultaneously, NHPA provisions that require consideration of CR where federal involvement occurs have led to the discovery and preservation of previously unknown CR. Accordingly, the ES classification for the current time is "sustainable."
- Regarding the future, federal and state regulations concerning CR are expected to remain in place and help maintain a "sustainable" condition. During each year of this study, additional resources will become eligible for possible placement on the NRHP, although some SHPO professionals have observed that numbers of NRHP candidate properties may be limited due to societal trends toward disposability, tear down, and sprawl. Additional riverfront development, including recreational areas, may result in covering or damage to CR near the land surface.

Positive trends related to CR include

- the development of predictive models to determine probability for CR occurrences
- recent emphasis on context integration of historic districts and
- an increasing number of river festivals and other events (e.g., the Lewis and Clark Commemorative Trail, Cincinnati's Tall Stacks, etc.) through which residents of the Ohio River Valley are rediscovering the rich cultural heritage of the river

FIGURE 12-2
ES of Cultural Resources



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Chapter 13
ADAPTIVE MANAGEMENT FOR THE OHIO RIVER

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13.2 INTRODUCTION

An emerging theme for strategic-level or programmatic environmental impact studies is use of an Adaptive Management (AM) approach to address large-scale issues and long future timeframes that involve both policy and scientific uncertainties. AM refers to a relatively new concept that recognizes that scientific uncertainties and unforeseen environmental changes are inevitable when various plans, programs, or policies are implemented in particular environmental settings. Interest in AM has developed in response to the perceived limitations of natural resources management approaches in the US and around the world and also may reflect a growing realization of the limits of science and engineering to solve complex public policy problems (National Research Council 2004). Accordingly, the application of the concept in environmental management entails:

> "...the use of carefully designed and monitored experiments, based on input from scientists, managers, and citizens, as opportunities to maintain or restore ecological resilience and to learn more about ecosystems. These actions are monitored for scientific findings to help improve understanding of how policy decisions affect ecosystems. Findings from ecosystem monitoring are then to be used to appropriately adjust management policies. Adaptive management requires that clear goals and desired outcomes be established so that progress toward desired future conditions can be assured." (National Research Council, 2002)

AM has been applied, or is being considered for application, in environmental management efforts related to several large-scale water resources projects and programs. For example, it is included in the Comprehensive Everglades Restoration Plan in Florida, the Glen Canyon Dam in Arizona, the Upper Mississippi River Basin navigation study in the Midwest, and the Coastal Louisiana project; and it has been proposed for the Missouri River Basin ecosystem management program.

Applying AM concepts to the Ohio River system acknowledges uncertainties and offers a systematic way for stakeholders, the Corps, and other federal agencies to explore the relationships and trade-offs between river ecology, navigation, recreation, and other uses. A post-ORMSS AM program could include periodic reviews of navigation traffic relative to the Corps' traffic growth scenarios and adjustments in planned investments for lock replacements, maintenance, and rehabilitation. Such a program could also include monitoring of environmental indicators and adjustments to navigation traffic management and environmental policies, as appropriate (Canter and Swor 2003).

13.3 ELEMENTS IN AN ADAPTIVE MANAGEMENT PROGRAM

Like a functioning AM program, the theories and concepts related to AM represent a work in progress. There is no prototype for AM implementation or standard format that will assure success, because AM is context-specific. Further, recognition and acceptance of uncertainty in AM enhances learning in ways that contribute to the uniqueness of each AM program. Nevertheless, several key elements are associated with AM in general and are applicable to an AM program for ORMSS (See National Research Council 2004; Canter and Swor 2003: Gunderson, 1999; Light 2001; and Walters 1986). These key elements include, but are not limited to:

- The assembly of information on historical and current conditions of key indicators for environmental resources that are potentially subjected to impacts from a plan, program, or project; along with quantitative prediction or qualitative description of these anticipated impacts, along with impacts from other past, present, and reasonably foreseeable future actions (i.e., the cumulative effects), on key indicators. Many factors should be included in the assessment and management process: environmental, ecological, economic, historical, political, physical, social, and cultural.

- Active involvement of a spectrum of stakeholders. Common ecological management goals should be socially defined through a collaborative vision process that involves all interested participants and that incorporates ecological, economic, and social considerations. Flexibility and commitment of stakeholders over a long timeframe are critical to the success of an AM program.

- Multiple quantitative models can be used to generate hypotheses about the system under consideration. The models, however, cannot substitute for the realities of field testing. Large, complex systems, such as the Ohio River, are constantly changing and are inherently uncertain with potential multiple futures.

- A range of management options linked to appropriate temporal and spatial scales. Because data rarely point to a single "best" management policy, the range of management options for each decision should be considered at the outset in light of stated objectives and models of system dynamics.

- A scientifically-designed monitoring program focused on measuring changes in key indicators of environmental resources subjected to potential cumulative effects. Monitoring should help distinguish between natural perturbations and perturbations caused by management actions.

- A strategic framework that includes periodic evaluations of the implementation of features of the System Investment Plan (SIP), the monitoring data and other related policy information, and decision-making, as appropriate, relative to adapting management policies or measures for the environmental resources of concern. Through such a strategy, AM becomes an iterative process in which management objectives are regularly revisited and revised accordingly.

- Collaborative long-term agreements among pertinent federal, state, tribal, and local environmental agencies; along with a program steering committee comprised of representatives from these agencies. Given that most ecosystems and watersheds transcend conventional geopolitical boundaries, ecological management requires coordination among federal, state, tribal, and local governmental entities, as well as collaboration with other interested parties.

- Adequate budgetary and personnel resources. Given the finite nature of public funds and other resources, ecological management enables agencies to engage in careful targeting to select achievable goals and to allocate resources efficiently.

- A peer group of reviewers with expertise in public policy analyses, planning and conducting environmental monitoring and research, and environmental decision-making.

- A commitment to learning. This is the essence of adopting an effective AM program and ensuring transferability of acquired knowledge to future efforts.

Each of these elements are being considered, as appropriate, in the AM program for ORMSS.

13.4 SITUATIONAL CONTEXT FOR AM OF THE OHIO RIVER SYSTEM

13.4.1 Regulatory and Rulemaking Foundations for Adaptive Management and Monitoring

Although AM and monitoring have developed slowly and only recently begun to receive widespread attention, elements of this approach can be found in the original language of NEPA, which includes policy '...to create and *maintain* conditions under which man and nature can exist in productive harmony...' (Section 101(a) of NEPA). Section 102(2)(B) calls for 'methods...which will insure that presently unquantified environmental amenities and values may be given appropriate consideration...' Section 102(2)(C) specifies that an EIS shall include 'the relationship between local short-term uses of man's environment and the *maintenance* and enhancement of long term productivity...' The CEQ is to define and *analyze* changes in the environment and interpret their causes (Section204(6))," (NEPA, 1969; Carpenter, 1997).

By 1974, CEQ noted very little progress towards improved understanding of ecological systems, finding that "ecological efforts were scattered throughout the government with little coordination or definition of priorities. 'Without a federal focus, response to problems which require ecological information or capability will continue to

be fragmented, costly, redundant, and reflexive rather than strategic, efficient, and contributory to national goals and productivity'" (CEQ, 1974; Carpenter, 1997). However, CEQ regulations did not directly address elements of AM and monitoring until 1992: "a monitoring and enforcement program shall be adopted and summarized where applicable for any mitigation" (Section 1505.2(c)) and "agencies may provide for monitoring to assure that their decisions are carried out and should do so in important cases" (Section 1505.3) (CEQ, 1992; Carpenter, 1997).

The CEQ again addressed the potential for using AM in the NEPA process in 1997, concluding that a "major difficulty with the traditional environmental impact analysis process is that it is a one-time event; i.e., results from intensive research, modeling, and other computations or expert opinions are analyzed, the analysis of potential environmental impacts is prepared, mitigation measures are identified, and a document is released for public review" (CEQ, 1997). Unfortunately, this process does not account for unanticipated changes in environmental conditions, inaccurate predictions, or subsequent information that might affect the original environmental protections. By incorporating the AM model into the NEPA process, the traditional "predict-mitigate-implement" model was expanded to incorporate the "predict-mitigate-implement-monitor-adapt" model. Although not all Federal actions lend themselves to incorporating AM into the NEPA process, the CEQ 1997 task force focused on certain actions where AM would be an appropriate model for the NEPA process to provide agencies with another tool to improve their NEPA implementation (CEQ 2003).

The CEQ 2003 NEPA Task Force initiated agency interviews and review of public comments anticipating that CEQ's 1997 NEPA effectiveness study had fostered an understanding of the value of integrating AM into the NEPA process. However, the Task Force discovered that incorporating AM into the NEPA process was a relatively new concept for many NEPA practitioners. The 2003 study also found that some agencies had applied the term AM to programmatic NEPA documentation, but without integrating 'monitor & adapt' components. This approach can result in a series of NEPA analyses that incorporate only the predict-mitigate-implement model. The 2003 Task Force also concluded there was strong consensus among agencies that guidance was needed in integrating AM into NEPA documents. The Task Force report recommended that the CEQ convene an AM work group to consider revising existing regulations or establishing new guidance to help agencies in exercising the option of incorporating AM into their NEPA process. Further, it was recommended that the CEQ should compile all guidance and regulations pertaining to AM in a handbook.

13.4.2 Monitoring and Adaptive Management in the Corps of Engineers

The Corps has established a leadership role in the application of AM, despite impediments from both internal and external sources. This progress stems in large part from Congressional action in the 1990s that added an ecosystem restoration mission to the Corps' responsibilities. As previously stated in 13-2, examples of AM applications include the Florida Everglades ecosystem restoration program, plans to restore Louisiana's coastal ecosystems, and applications in the Upper Mississippi and Missouri River Systems.

13.4.3 Planning Guidance

Several Corps guidance documents address some aspect of monitoring and AM (Laufle, 2003). The most extensive discussions appear in ER 1105-2-100 (Planning Guidance Notebook, 22 April 2000) and EC 1105-2-210 (Ecosystem Restoration in the Civil Works Program, 1 June 1995).

Corps guidance cites the "relative newness of restoration science and uncertainty in ecosystem restoration planning, theories, and tools" and the potential applicability of AM "in restoration projects recognized during planning to have the potential for uncertainty in achieving restoration objectives." Monitoring is called for "when new, unproven restoration techniques are being applied, and when significant levels of uncertainty prevail at the time of implementation" (EC 1105-2-210).

However, all the Corps guidance tends to categorize monitoring and AM as exceptional measures outside the normal realm of operations, to be employed only when special circumstances warrant. Monitoring is generally confined to examination of post-construction effects for a limited period of time (e.g., not to exceed 5 years) and within a limited budget (e.g., 1% of total first cost of ecosystem restoration features). AM, with a budget limited to 3% of total project costs excluding monitoring, may be recommended only for complex projects that have high levels of risk and uncertainty of obtaining the proposed outputs.

The NRC notes that Corps planning guidance and procedures contain few direct references to AM principles. The *Principles and Guidelines for Water and Land Resources Implementation Studies* (often referred to as the *"Principles and Guidelines"* or *P&G*), and the Corps *Planning Guidance Notebook* (or PGN; USACE, 2000a), also known as ER 1105-2-100 are largely based on concepts that pre-date the emergence of formal AM strategies. AM's emphasis on uncertainties, learning, and flexible policies represents a departure from the Corps' traditional planning approaches, and AM principles have only begun to be incorporated into the agency's planning guidance (NRC, 2004).

13.4.4 Environmental Operating Principles

Recognition of inadequacies in the Corps' guidance documents contributed in part to promulgation in March 2002 of the Corps' Environmental Operating Principles, which are intended to guide the Corps in all of its work. Many aspects of the AM approach are recognized, at least implicitly, in these principles. They include:

- achieving environmental sustainability
- recognizing the interdependence of life and the physical environment
- seeking balance and synergy among human development activities and natural systems
- seeking ways to assess and mitigate cumulative impacts on the environment
- bringing systems approaches to the full life cycle of Corps' processes and work, and
- building and sharing an integrated knowledge base that supports a greater understanding of the environment and impacts of Corps activities.

The commitment of the Corps to fully integrate the Environmental Operating Principles into all aspects of Corps programs and operations was reinforced by issuance of

EC 1105-2-404 "Planning Civil Works Projects under the Environmental Operating Principles" on 1 May 2003. Further reinforcement came with issuance of ER 200-1-5 "Policy for Implementation and Integrated Application of the U.S. Army Corps of Engineers (USACE) Environmental Operating Principles (EOP) and Doctrine" on 30 October 2003. The purpose of these documents is to "reaffirm the USACE general policy and further describe specific procedures.....consistent with environmental sustainability as defined in the Corps Environmental Operating Principles and Implementation Guidance."

13.4.5 Strategic Plan

The Corps' Civil Works Strategic Plan of March 2004, describes five national water resources challenges:

1) Achieving greater balance between traditional water resources demands and environmental/ecosystem objectives
2) Restoring the vitality of the environment from degradation caused by past development
3) Addressing the performance and safety implications of an aging water resources infrastructure
4) Ensuring the capability to respond to natural disasters and terrorism threats to water resources infrastructure, and
5) Minimizing institutional barriers to efficient and effective water resources planning, decision making, and management.

These challenges incorporate several recommendations found in recent NRC/NAS studies conducted for the Corps. The Plan also states that "it is beyond the scope and capability of any single agency to solve these challenges. We need innovative and collaborative ways to stretch resources and capabilities. The approach advocated in this strategic plan emphasizes:

- A holistic focus on water problems and opportunities
- Attention to the watershed as a logical geographic area for managing water resources
- A systems approach for analyzing problems and solutions
- Collaboration, partnerships, and teamwork for deriving and implementing solutions, and
- An emphasis on efficiencies to achieve more within existing resources.

Finally, three of the five goals of the Plan address issues relevant to AM:

Goal 1 - Provide sustainable development and integrated management of the Nation's water resources.

Goal 2 – Repair past environmental degradation and prevent future environmental losses.

Goal 3– Ensure that projects perform to meet authorized purposes and evolving conditions.

While the Strategic Plan does emphasize sustainable development and mentions AM, no detailed discussion is included. However, many listed strategies for Goals 1 through 3 are associated with "good practices" related to AM. Examples of "good practices" include collaborative planning and evaluation efforts with other governmental agencies and stakeholder groups, information dissemination, and adjustments to changing conditions via the AM process.

13.4.6 NRC Recommendations

Further evidence of commitment to implementing AM is evidenced by the Corps' request to the NRC for a study and recommendations addressing AM in the Corps. The NRC's AM panel was tasked to:

> Review the Corps of Engineers' efforts in applying AM concepts to project and program planning and operations, identifying AM's potential and its limitations. The panel will consider the range of Corps of Engineers' responsibilities that relate to AM concepts, including ecosystem restoration, flood damage reduction, and navigation enhancement. The panel will review the Corps' methods for implementing and practicing AM and will identify barriers to implementing the concept. The panel will also recommend ways in which AM might be usefully applied in Corps project planning and operations (NRC 2004).

The NRC report notes that AM is a multi-disciplinary, evolving concept whose core principles emphasize concepts such as uncertainty, surprise, and resilience. These concepts run counter to traditional engineering planning concepts of deterministic systems, precision, and model predictions. AM stresses the value of variability and extremes in sustaining healthy ecosystems. The Corps, on the other hand, has long sought to reduce hydrologic variability by providing reliable navigation channels, reducing high flows, and stabilizing coastal areas and beaches. AM will thus entail changes in operational styles and in organizational accountability as well as changes to Corps guidance, staffing, and procedures.

The NRC report also noted that the following opportunities may result from implementation of AM by the Corps:

- AM practices can be relevant and useful across a variety of scales and settings. In tracking experiences with AM, the Corps will benefit by a better understanding of the settings in which an adaptive approach—which may not always be appropriate—is merited and useful.

- AM may be particularly suited to large, complex ecosystem restoration projects, which entail large degrees of risk and uncertainty, multiple, and changing objectives, and phased components. AM can be especially important in multi-phase activities, as it can promote adaptation of ends and means based on lessons learned that lead to model improvements to support future decisions.

- AM entails a spectrum of approaches. These range from "passive" programs, which focus on monitoring and evaluating outcomes from a particular policy choice, to more formal and rigorous "active" AM, which designs management actions to test competing models of system behavior so that models can be improved for future decision making. Ever-improving guidance could help provide advice concerning the degree to which AM is applicable to various types of projects. This could range from limited monitoring programs (passive) to more formal (active) AM programs with carefully-structured operational alternatives and ecosystem models.

- Although AM has been linked primarily with natural resources management, it can be used to manage other types of systems. AM concepts could thus be useful within the Corps' navigation and flood management programs, as well as to its efforts in ecological restoration. Additionally, AM could be applicable in broader, but smaller scale settings such as small projects, infrastructure management (includes dam decommissions), and permitting activities. Recommendations for these broader applications include the following:

  Small Projects Authority: Small project programs are excellent candidates for experimentation and concerted learning in connection with AM efforts. The Corps has the ability to change administration of these programs to allow for cost-shared modifications in project features based on long-term monitoring results of physical project outputs and ecological outcomes. Such changes would require no additional congressional authority. These changes could generate important demonstrations of the value of AM and provide a basis for seeking additional congressional authority to revisit completed and ongoing projects that could benefit from AM. Such settings would also allow the Corps to gain experience with smaller-scale and less controversial projects, lessons from which could be valuable in their efforts in more controversial situations.

  Managing Existing Infrastructure: Effective operations of existing dams and other water resource infrastructure in the United States presents a challenge and an opportunity to the Corps and other federal water management agencies, as well as state and local governments and non-governmental organizations. Three key issues in management of this infrastructure could benefit from management criteria or guidelines that incorporate AM: (1) monitoring and evaluating dam and project performance; (2) retrofitting, redesigning and operating dams to improve infrastructure safety and project performance; and (3) decommissioning, where warranted by costs and benefits. The Corps, with its varying involvement in design, permitting, construction, and operation of many of these structures, is the logical agency to assume the necessary responsibilities.

  Passage of the Dam Safety and Security Act in 2002 points to increased congressional concern for dam safety issues. The Federal Emergency Management Agency (FEMA) coordinates federal dam safety efforts, helps finance research, coordinates technology transfer, and assists states with their dam safety programs (which cover approximately 95 percent of dams listed in the National Inventory of Dams). FEMA is not responsible, however, for improving dam safety technology or the engineering and science on which that technology is based. That would be a logical responsibility for the Corps, in cooperation with other organizations.

  A promising area of application of AM involves dam decommissioning and de-authorization. Although a dam cannot be incrementally removed, adaptive learning based upon the experiences with past dam removals should be used to refine the criteria and approaches for removals, and to

improve methods for post-removal mitigation. As the Corps' Inventory of Dams describes, over 75,000 dams have been erected on U.S. waterways, many of which are outdated, unsafe, and no longer active. Some of these structures have also caused significant impacts on river ecosystems. In recent years, the decommissioning and removal of dams has become more common. Hundreds of U.S. dams were removed in the 1990s, and removal of many more is being considered. Not all of these are small structures. A seminal case was the Quaker Neck Dam on North Carolina's Neuse River, where the Corps worked with the U.S. Fish and Wildlife Service and other federal and state agencies to remove a dam that had blocked migratory fish routes since 1952. In addition to ecological impacts, maintenance of Quaker Neck Dam had become hazardous and expensive. After the Corps designed alternative means of providing cooling water to the related power plant, a cooperative effort resulted in dam removal in 1997-98.

Permitting Activities: AM could also be usefully applied to the Corps' permitting activities. For example, the Corps is responsible for evaluating applications for wetland fill permits under the Clean Water Act Section 404. Corps regulations prohibit any filling unless appropriate and practicable steps have been taken to minimize adverse impacts on aquatic ecosystems. When the Corps issues a permit, it requires that discharges to wetlands be avoided or minimized to the extent practicable. Remaining impacts must be mitigated, often through compensatory mitigation, in which other wetlands are created or restored. A previous NRC committee concluded that compensatory mitigation was not fulfilling its goal of achieving no net loss of wetlands because clear performance standards were not being defined within permits and performance was not being monitored (NRC, 2001a). Although detailed evaluation of the regulatory program is beyond this report's scope, AM principles could help the Corps improve its wetland mitigation program. Performance goals could be set in permits, and permitees could be required to implement a monitoring program focused on wetland functions. Alternatively or additionally, the Corps could conduct a retrospective study(s) of mitigation projects, and use the results to improve design of future mitigation efforts. AM principles could also be used to guide permitting decisions and mitigation requirements in which cumulative impacts are an issue, such as where multiple permits are issued for the same water body.

13.4.7 Stakeholder Collaboration

The NRC report also notes that Corps' successes with stakeholder participation appear to be paying some dividends. In the Upper Mississippi, the agency's responsiveness to stakeholder input may be enhancing public trust in the agency. By contrast, a lack of this type of support for broad, meaningful stakeholder participation may be contributing to decision making gridlock on the Missouri River.

There is much to be learned about how to successfully incorporate the concept, and the Corps should continue to move forward in its collaborative efforts. The agency could, for example, publicize examples where stakeholder-driven AM actions led to beneficial effects that were largely unanticipated, and seek to learn from past experiences throughout

the agency. Stakeholder and agency involvement should begin at the onset of AM programs and should include stakeholder participation in periodic review of monitoring results and management models.

13.4.8 Institutional Constraints

Despite considerable progress to date, the NRC report also identifies a number of internal factors that can inhibit successful implementation of AM. The Corps' highly decentralized organization offers one significant impediment. A drawback of this structure is that district offices focus largely on planning their own new projects and working closely with local project sponsors, without benefiting from the knowledge and experience of colleagues in other district offices. There are limited incentives and resources, and few precedents or traditions, for district offices to seek information from one another or from experts outside the organization, or to communicate lessons from their experiences throughout the organization. Although many Corps district offices and personnel are pursuing AM activities, these experiences are not being explicitly shared throughout the agency.

In many ways, AM represents a departure from traditional Corps planning approaches and disciplinary strengths. The Corps is in the midst of a broad shift from construction toward increased emphasis on operating a large, existing infrastructure, which controls a large portion of the nation's hydrologic systems and distributes significant benefits. The Corps must maintain its engineering expertise to safely operate this infrastructure, but sound management of Corps' projects today also calls for expertise in fields such as ecology and economics.

AM is consistent with this broadening mission and it represents a promising means for making better decisions under uncertainty and facilitating stakeholder cooperation and input. It aims to fuse knowledge and understanding of economics and other social sciences, engineering, and ecology. Just as important as broadening disciplinary expertise is the incorporation of these broader perspectives within Corps decision making. Enlisting experts in social and ecological sciences, or commissioning studies in these areas, is of little use if the agency does not have the appropriate capacity to meaningfully incorporate these perspectives and knowledge into the project planning and management cycle.

A broader range of personnel and disciplinary perspectives should be included within all phases of project management in order to implement AM within the agency. For example, some Corps staff members are occasionally involved in projects and tasks that transcend their expertise, such as when engineers are asked to conduct economic analyses or to facilitate public meetings regarding controversial studies or projects. Moreover, there is no evidence that AM efforts in district offices are proceeding consistently in accord with a set of guiding principles, or with sharing experiences and knowledge across district offices or throughout the agency. Not every Corps office need employ experts from a wide range of disciplines, but the Corps needs broader expertise that its staff can turn to in implementing and sustaining AM practices. One proposal worth further consideration is the creation of a small center specializing in AM housing an interdisciplinary team to provide advice to all Corps offices and to synthesize results of the Corps' AM efforts across the nation.

13.5 DIFFERENCES BETWEEN ADAPTIVE MANAGEMENT AND TRADITIONAL MANAGEMENT APPROACHES

Because AM represents a departure from traditional planning approaches and disciplinary strengths, several conceptual barriers to its implementation may arise. Defenders of the status quo, for example, may view AM as indicating failures of past decisions; some may view it as a means of circumventing environmental and other standards or as an excuse for taking minimal actions, and budgeters may be concerned about the costs of related monitoring and science-based programs.

Decisions made within traditional management systems may be difficult to change because managers may resist recognizing and learning from their own errors. AM can help reduce decision-making gridlock by emphasizing that decisions are provisional, often with no "right' or "wrong", and that modifications are expected (NRC 2004). The multi-faceted, collaborative framework of AM promotes the search for common ground and goals definition, which should ease the tension of agencies or individuals who perceive their interests are at risk. This in turn enhances cooperation among participants.

A 1997 CEQ review of the effectiveness of NEPA after 25 years concluded that a major difficulty with the traditional environmental impact analysis process is that it is a one time event. Consequently, such a process does not account for unanticipated changes in environmental conditions, inaccurate predictions, or additional information that might affect the original environmental analyses. By incorporating AM into the NEPA process, the CEQ suggests that the traditional "predict-mitigate-implement" model can be expanded to a "predict-mitigate-implement-monitor-adapt" model.

13.6 ADAPTIVE MANAGEMENT – A USEFUL APPROACH FOR THE OHIO RIVER SYSTEM

The reality of changing conditions which AM recognizes is especially relevant to public works projects measured in decades. For example, the Ohio River system, as studied in the System Investment Plan (SIP), extends through the year 2070. Among many reasons AM is a useful approach for the Ohio River system are:

1) It is a large system which transcends conventional geopolitical boundaries and requires coordination among federal, state, and local agencies, Non-Governmental Organizations (NGOs), etc., (Canter 2003 in Woolpert compilation).

2) Ecological management policies and decisions should be based on integrated and scientific information that addresses multiple resources, such as that provided in the ORMSS Cumulative Effects Assessment (CEA), rather than addressing single resources (Canter 2003).

3) Given finite public resources for possible environmental mitigation and restoration projects along the Ohio River, AM is a way for agencies to allocate resources efficiently to affect measurable results.

4) AM recognizes the scientific uncertainty that occurs in large river systems such as the Ohio River. There may be opportunities to apply lessons learned from AM programs for other large river systems in the US that could be applied to the Ohio River.

5) AM does not postpone actions until enough is known, but enables learning and action despite limitations, even taking advantage of unanticipated events (Lee 1999). Accordingly, momentum gained during the ORMSS process can be a catalyst to launch a long-term AM program.

6) AM can increase the ability to respond in a timely fashion to new information concerning the Ohio River, in part because stakeholders and other institutional structures are already in place.

7) AM can reduce decision-making gridlock by making it clear that decisions are provisional (NRC 2002). The climate of trust developed by the Interagency Working Group (IWG) during ORMSS meetings over several years could facilitate group decision-making in a future AM program.

8) AM promotes monitoring that focuses on significant and detectable indicators of progress towards management objectives (NRC 2004). Many indicators were identified during the ORMSS CEA process, while other indicators and indices are under development or are being studied by ORSANCO and other organizations.

9) AM is compatible with the developing science of ecosystem restoration embodied in the Corps Environmental Operating Principles (EOPs) and outlined in the Ohio River Ecosystem Restoration Program (2000). It is important that the Corps allocate sufficient funds to monitor effects of future restoration efforts and generate and disseminate information that will enhance success of these efforts.

10) Because AM supersedes smaller spatial and temporal scales and individual projects, it focuses on the interconnectedness of resources as is emphasized in the CEA. Likewise, the holistic, multi- and interdisciplinary nature of AM integrates Ohio River Valued Environmental Components (VECs).

11) AM considers the cumulative effects that occur in river basins that, like the Ohio, are exposed to multiple stressors both from human activities and natural disturbances such as storms and floods.

12) AM goes beyond piecemeal environmental mitigation to consider hydrological processes, sediment transport, and other dynamics driving the river ecosystem (Light 2001). The ORMSS CEA has sought to integrate these processes.

13) Finally, in addition to ecosystem applications, operation of existing locks and dams on the Ohio River could benefit from guidelines that incorporate AM.

13.7 THE ROLE OF MONITORING IN ADAPTIVE MANAGEMENT

As suggested previously, a key feature of AM is planning and implementation of monitoring programs aimed at addressing identified environmental uncertainties. Sadler

and Davies (1988) describe three types of environmental monitoring which might be associated with the life cycle of a plan, in this case, the SIP. These include baseline (current conditions) monitoring, effects or impact monitoring, and compliance monitoring. Baseline monitoring is measurement of environmental variables during a representative pre-project or pre-plan period to determine existing conditions, ranges of variation, and processes of change. Effects or impact monitoring involves measurement of environmental variables during construction and operation of one to several projects to determine changes that may have been caused, and to develop or evaluate mitigation measures. Finally, compliance monitoring takes the form of periodic sampling and/or continuous measurement of levels of waste discharge, noise, or other emissions, to ensure that conditions are observed and standards are met. It could also include compliance auditing with regulatory permit programs of the USEPA, the Corps, and the involved states. Pre-Programmatic Environmental Impact Statement (PEIS) monitoring includes baseline monitoring, while post-PEIS monitoring encompasses effects or impact monitoring, and/or compliance monitoring. All three types of monitoring should be included in an AM program for the Ohio River. Several monitoring programs already in progress for the Ohio River are described in the following section on implementing an AM program for the Ohio River.

Careful planning and implementation of a monitoring program is necessary for meeting the various purposes of monitoring. Three considerations are important in planning monitoring programs in the United States. First, there is an abundance of environmental monitoring data routinely collected by various governmental agencies and the private sector. These data need to be identified, aggregated, and interpreted since information is often compiled but never interpreted relative to the quality of the environment being monitored. Second, because environmental monitoring programs are expensive to plan and implement, every effort should be made to use or modify extant monitoring programs. Third, owing to overlapping environmental management and monitoring responsibilities of many local, state, and federal governmental agencies, it will be necessary to carefully coordinate environmental monitoring planning with several agencies.

To illustrate the scientific considerations that may be involved in planning a monitoring program, a generic seven-step conceptual framework for developing a plan is highlighted (Spellerberg 1991). The framework can be adapted to monitoring environmental media and socioeconomic and/or social impacts. The following describes the 7 steps described by Spellerberg:

1. Step1 is to define the monitoring objectives. In many monitoring schemes, the objectives are either not stated or are so complex that they become meaningless.
2. Step 2 is to determine the spatial locations where the monitoring will take place.
3. Step 3 is to make sure the data collected are documented for future use. When monitoring programs extend over long periods of time, such as for the SIP, professionals working on the AM program will change. Therefore, the need arises for methods to assure retention of such data, which should be accessible and understandable to successive professionals.
4. Step 4 entails various arrangements for data collection and storage. The success of a monitoring program depends not only on good planning and logistical support, but also on coordination with other related programs.

5. Step 5 involves the process of selecting the indicators to be measured. The ideal indicator and process would be completely field-based, but logistic limitations (finances, time, and effort) may override these considerations. Due to such logistic limitations, methods for collection of data from the field or assemblage of data from other sources should therefore be considered along with the choice of indicators. Monitoring data can be aggregated into pertinent indices to reflect the composite quality of different environmental categories. For example, several indices for the biological environment have been developed, including indices of biotic integrity (IBIs) for stream fish assemblages. CEA Chapter 4 – Fish, describes the Ohio River Fish Index (ORFIn), which ORSANCO recently has developed for the Ohio River.
6. Step 6 involves preliminary data gathering and baseline surveys. Before biological monitoring starts, information from published sources or preliminary field studies should be assembled.
7. Step 7 involves analysis and presentation of the data. Who will use the data to make management recommendations should be considered when the form of data presentation is selected. For an AM program, it is anticipated that the program steering committee will use the information to adapt management efforts, as appropriate.

13.8 RESOURCES FOR IMPLEMENTING AN ADAPTIVE MANAGEMENT PROGRAM FOR THE OHIO RIVER SYSTEM

Implementation of an AM program for aquatic and riparian/floodplain resources of the Ohio mainstem could be facilitated by a framework already in place, which encompasses institutional relationships, monitoring programs, ecosystem and economic models, and various educational efforts. The following section describes the components comprising this framework and their potential applications to an AM program for the ORMSS study area.

13.8.1 Organizations with Coordinating Roles Related to Ohio River Management

No long-term entity for AM of the Ohio River system has been established; however, several organizations and agencies currently are involved in various aspects of Ohio River management. Development of the ORMSS CEA has provided opportunities to become better acquainted with these organizations and their missions.

The lead agency for ORMSS, the Corps, is the federal agency responsible for planning, construction, operation, and maintenance of navigation structures along the Ohio River. Additionally, the role of the Corps has expanded in recent years to include ecosystem restoration. The Corps cannot typically carry out these projects by itself, however, since current authorities require a non-federal cost sharing partner.

Recognizing limitations within their agency, the Corps' Environmental Planning Team for ORMSS, developed an Interagency Working Group (IWG) to help identify scientific information and guidance for the CEA process. The IWG consists of approximately 40 members representing federal and state agencies, as well as several NGOs. Agencies and organizations represented on the IWG include the U.S. Fish & Wildlife Service, U.S. Geological Survey, U.S. Environmental Protection Agency, Ohio

River Valley Water Sanitation Commission (ORSANCO), along with several state resource agencies and NGOs. It may be appropriate for the IWG, which has coalesced over several years, to continue their involvement with the Corps by serving a similar role with the Ohio River AM even beyond completion of ORMSS because of the IWG's grounding in AM issues through participation in:

- Identifying key issues and cumulative effects for the Ohio River system
- Delineating and prioritizing key research needs relative to environmental issues and natural resources
- Identifying scientific information on emerging issues throughout the ORMSS process, and
- Participating in early stages of the planning and implementation of a long-term strategy for environmental monitoring and AM for aquatic and riparian/floodplain resources within and along the Ohio River mainstem.

The synergy and ideas generated by this group are important assets that support the concept of continuing the IWG as part of a long-term decision-making body instrumental to AM program implementation. Additional access to data and institutional knowledge is available though several IWG members who serve on the following specialized resource management teams for the Ohio River:

1) The Ohio River Fisheries Management Team (ORFMT), a group including representatives from fisheries resources agencies of the six states bordering the Ohio River. Activities of ORFMT have included coordination of state fishing regulations, development of management plans for sport fishes and species of special concern and, more recently, participation in developing an Asian carps management/control plan.

2) The Ohio River Valley Ecosystem Team (ORVET) consists of U.S. Fish & Wildlife personnel participating in eight subgroups relevant to Ohio River ecosystem management, including wetlands, migratory birds, fisheries resources, mollusks, endangered species, law enforcement, outreach, and cave/karst habitat. The ORVET has an extensive network of cooperators including universities, NGOs, and state resource agencies.

3) Because of its long-term role in resource monitoring and promulgation of standards on the Ohio River, ORSANCO is an important collaborator in an AM program for the river. Since its creation in 1948 though an interstate compact aimed at controlling pollution and improving the river's water quality, ORSANCO's programs have grown to include extensive monitoring, spill prevention and detection, fish consumption and recreation advisories, TMDL development, river cleanups, and public outreach. Its multi-state governing body provides a forum for interstate issues and policies and opportunities for interactions with federal agencies and funding authorities. The role of ORSANCO will be expanded upon in subsequent sections on monitoring, modeling, and education.

4) The Ohio River Basin Commission (ORBC) is another interstate group charged with coordinating and managing the water resources and related land resources of the Ohio River watershed. ORBC membership consists of gubernatorial representatives from nine participating states; the ORBC also has a Citizens' Advisory Council. In

addition to discussing and developing regional policies related to Ohio River resources, the ORBC seeks to encourage coordinated and cooperative actions among the participating states and federal agencies. Further, the ORBC represents interests of the Ohio Basin before Congress and federal agencies. The ORBC has not been represented in the IWG for ORMSS.

4) The Ohio River Basin Consortium for Research and Education (ORBCRE), an association of universities, colleges, industries, and agencies was established 20 years ago with the goal of promoting inter-institutional research and education in water related concerns and other environmental issues in the Ohio River Basin. Throughout the ORMSS, the environmental study team has actively participated in ORBCRE events.

13.8.2 Models and Other Tools Applicable to Ohio River AM

Computer models, habitat indices, and other quantitative tools are inherent in successful AM programs. Development, evaluation, modification, and eventual application of such quantitative tools in AM distinguishes the directed learning characteristic of AM from the more evolutionary trial-and-error approach to ecosystem management. Applying modeling and other tools to the AM process helps focus management options and identify alternatives for further evaluation and testing (Walters 1997).

Lee (1999) and others have emphasized that an explicit baseline understanding and assumptions about an ecosystem being managed can provide a foundation for learning by AM. Such a system model helps to explain responses to management actions and to identify knowledge gaps and limits (NRC 2004). Because it assesses cumulative effects for a spectrum of actions and identifies areas of uncertainty for further study, the ORMSS CEA in effect provides a model for the Ohio mainstem. Although qualitative in many respects, the ORMSS CEA offers future participants in an Ohio mainstem AM program a comprehensive, integrated understanding of the VECs or resources that compose the river system.

Walters notes that the "learning by doing" objectives of AM should begin with "a concerted effort to integrate existing interdisciplinary experience and scientific information into dynamic models that attempt to make predictions about the impacts of alternative policies" (Walters, 1997). This modeling step is intended to serve three functions:

(1) problem clarification and enhanced communication among scientists, managers, and other stakeholders;
(2) policy screening to eliminate options that are most likely incapable of doing much good, because of inadequate scale or type of impact; and
(3) identification of key knowledge gaps that make model predictions suspect."

In this context, characterization of past to present conditions, current trends, and predictions of environmental sustainability for individual VECs provided by the ORMSS CEA provides a close approximation to Walters' description of a dynamic model appropriate to an AM approach.

In contrast to the ORMSS CEA, many ecosystem and hydrological models applied to AM are numerical, in which elements and processes of a given system (e.g., river corridor)

are quantitatively expressed within a computer program. The more accurately such models are able to simulate reality, the greater their credibility. Field testing of ecosystem models is critical, however, because model results should neither be equated with reality nor viewed in isolation from other integrating factors (NRC 2004).

Three quantitative assessment tools with applications to AM are currently under development or evaluation for the Ohio mainstem. These tools, which conform to the above criteria, are briefly described as follows:

1) NAVPAT

As discussed in further detail in Chapter 4 Fish of this CEA, over the past 20 years, the Corps- Louisville District developed the Navigation Predictive Analysis Technique (NAVPAT) model to assess potential incremental habitat effects of various navigation planning scenarios. The goal of NAVPAT is to provide quantitative results, which can assess positive or negative changes in available aquatic habitat quality for a specific area of a river cross-section or for an entire reach of river. In general, NAVPAT links tow movements to possible biological effects, which result from habitat disruption. The NAVPAT model consists of four primary input components: river reach characteristics, traffic scenarios, physical forces, and biological species life-stage models.

2) ORFIn

Also discussed in Chapter 4, the Ohio River Fish Index (ORFIn), an index of biotic integrity (IBI) developed by ORSANCO and other agencies during the past several years, is specifically tailored to the distinctive ecological characteristics of the Ohio River. The ORFIn measures 13 attributes of fish communities that either respond predictably to measures of human disturbance or reflect desirable features of the Ohio River. ORFIn is sensitive to a wide range of habitat and water quality conditions and is being used to develop numeric biological criteria for the Ohio River for eventual incorporation into ORSANCO's Pollution Control Standards (Emery and Vicory 1998). Evaluation and refinement of ORFIn as a sustainability assessment tool will continue over the next several years.

3) ORNIM

The Ohio River Navigation Investment Model (ORNIM) is a tool specifically developed by the Corps to identify and evaluate the structural and nonstructural alternatives that yield the optimal combination of navigation capacity enhancement and nonstructural investments for the Ohio River system (Frechione & Walker 2003). As explained in Chapter 10, Transportation and Traffic. ORNIM is used to determine the proper mix of navigation improvement actions that maximizes economic return from Federal investments in the Ohio River System.

13.8.3 Monitoring Programs Applicable to Ohio River AM

As mentioned in the preceding section, ORSANCO has conducted a broad range of water quality and biological monitoring activities since the mid-20th century that have documented conditions and illustrated trends. ORSANCO's current monitoring activities focus on bacteria monitoring near six major urban areas along the river, fish and

macroinvertebrate monitoring, fish tissue sampling, metals sampling, detection of organics, and algae and nutrient sampling related to drinking water supplies and the development of criteria for nutrients.

Both ORSANCO and the University of Louisville are participating in the USEPA's Environmental Monitoring and Assessment Program (EMAP) which includes the Ohio River. EMAP's goal is to develop the scientific understanding for translating environmental data from multiple spatial and temporal scales into assessments of current ecological conditions and forecasts of future risks to natural resources (EMAP web site). Development of indicators to monitor the condition of ecological resources is one of several AM concepts incorporated into EMAP. EMAP's study of the Great Rivers of the central U.S. (encompassing the Upper Mississippi, Ohio and Missouri rivers) began in July 2004 and includes monitoring the Ohio mainstem. The Great Rivers EMAP is currently underway on the Ohio River.

Since the mid-20th century, regulated industries (including power companies, drinking water companies, and industrial waster dischargers) also have conducted studies of mussels and other resources (e.g., fish, bacteria, temperature, and pH) near their facilities along the river, often in collaboration with university researchers. Some of these studies were cited in the CEA; further, representatives of this sector contributed to discussions on aquatic and riparian sustainability during ORMSS. This sector will continue to perform impact assessments and compliance monitoring (e.g., studies related to §316(a)&(b) of the Clean Water Act) as required by their individual permits.

However, the uncoordinated accrual of data collected to meet permit requirements may have only marginal value to the system-wide focus of an AM program. Additional industry participation in collaborative development of an AM program for the Ohio River could result in restructuring of some aquatic studies conducted by this sector. For example, such restructuring could contribute to more effective monitoring of key indicators for mussels and other aquatic resources. As more information is assembled on the locations and characteristics of mussel beds in the mainstem, planning and implementation of targeted and long-term mussel monitoring programs can be more effectively accomplished. Further, the results can be used in an AM program focused on enhancing and maintaining the ES of the mussel resource.

13.8.4 Mapping Programs Applicable to Ohio River AM

Large-spatial mapping efforts also provide information of potential value to AM programs when such maps help identify trends and cumulative effects. Among such mapping efforts are the USGS/LANSAT/National map as well as the USFWS's National Wetlands Inventory (NWI) which produces information on the characteristics, extent, and status of U.S. wetlands. Geographical Information Systems (GIS), including systems developed by the Corps' Districts, can track permits, help identify spatial and temporal trends, and assess cumulative effects. Concurrent with these coordinated mapping programs are various efforts to improve the accessibility of such information to the general public.

13.8.5 Public Information Initiatives Applicable to Ohio River AM

Public education initiatives applicable to AM of the Ohio River mainstem potentially range from professional and university initiatives to environmental education activities for young students. At the research/higher education end of the spectrum is the Ohio River Basin Consortium for Research and Education (ORBCRE), an association of universities, colleges, industries and agencies established 20 years ago with the goal of promoting inter-institutional research and education in water related concerns and other environmental issues in the Ohio River Basin (www.ent.ohiou.edu/~orbcre/main1.html).

The organization's annual meeting may serve as a forum for introducing AM concepts and establishing initial priorities for a river-wide program. Several members of the ORMSS IWG either are directly affiliated with ORBCRE or attend its annual meetings.

Throughout development of the CEA, the ORMSS Environmental Planning Team contacted river researchers at several universities and identified projects relevant to AM of the Ohio River. A potentially relevant program recently developed is the Rivers Institute at Hanover College, Madison, IN. Three other institutions of higher learning – Marshall University, Thomas More College and the University of Louisville – either have research facilities on the Ohio River or plan to establish such facilities. Other efforts related to the Ohio River are underway at the University of Cincinnati, Northern Kentucky University, and Southern Illinois University,

Among the informal opportunities to learn about the Ohio River are those provided by:

- ORSANCO through its mobile aquarium, River Watchers school program, annual Riversweep, and other efforts,
- NGOs, including the Nature Conservancy and Ohio River Foundation, and
- Citizens' organizations such as the Riverlife Task Force (Pittsburgh), the Ohio River Way (Cincinnati) and River Fields, Inc. (Louisville).

13.8.6 Small Scale Applications of Adaptive Management

Small scale applications are an integral component of any AM program, regardless of the resource scales and timeframes being addressed. AM recognizes the need to implement actions at local, project specific levels and to link project managers to AM roles. Opportunities for lower costs, more flexible design, and quicker results can enhance the 'learning by doing' aspects of adaptive experimentation, point the way toward more promising approaches, and potentially demonstrate the value of continued support for the AM program.

Smaller scale approaches to impact analysis, restoration, and experimentation may also serve to enhance stakeholder participation. The use of pragmatic or 'conceptually accessible' models can allow virtually any group of stakeholders to assess:

- The scale/spectrum of resource impacts associated with proposed actions and alternatives,
- Impact tradeoffs of project alternatives or modifications,
- The context of project impacts relative to the broader spectrum of impacts affecting resources at local and system-wide scales,
- Feasibility of linkages between potential resource management actions and desired outcomes, and

- Accountability requirements to assess the degree to which desired outcomes are achieved

Implementation of an AM approach can potentially benefit from the synergistic effects of two 'alternative' strategies referred to as 'trickle down' and 'bubble up.' Trickle down starts from the large scale resource perspective (watershed, main stem corridor) and long time frame, and develops a resource model at this broad scale. This strategy works to:

- Develop a collaborative, multi-agency program approach,
- Identifies affected stakeholders (and may empower or assist some stakeholder participation), and
- Involves stakeholders in developing a description and model of resource issues, conditions, trends, and desired outcomes

These activities provide a framework for implementation of coordinated management actions at local, project specific scales.

The 'bubble up' approach starts from a local or grass roots perspective that recognizes the AM principle of taking action based on limited information and planning projects to learn from unanticipated outcomes. This approach includes an effort to identify and incorporate best available information about local issues in the context of broader resource management issues, often via case studies and various information networking strategies. The primary focus is to design and implement resource management strategies to meet local needs, but includes monitoring and documentation strategies to communicate the learned experience from the local focus to other settings.

13.9 AN ADAPTIVE APPROACH TO STAKEHOLDER INVOLVEMENT

13.9.1 ORMSS Environmental Sustainability (ES) Workshops – A Prototype for Future Stakeholder Activity

Two special workshops were convened during development of the ORMMS CEA to catalyze discussions leading to formulation of recommendations to improve environmental sustainability (ES) and initiate AM of the Ohio River system. Although these special workshops focused on aquatic and riparian/floodplain resources, they served as prototypes for stakeholder involvement while demonstrating that a similar participatory approach can be applied to any VEC.

As the process unfolded, it became apparent that the special workshops and collaborative thinking they generated were consistent with the key elements of AM in several important respects:

- Workshop participants represented a broad spectrum of stakeholders from state and federal agencies, universities, and electric utilities. The workshops were designed to engage participants in a collaborative visioning process that incorporated ecological, economic, and social considerations.

- Although individual participants had distinct interests, they comprised a cohesive peer group with expertise in public policy, planning and conducting environmental

research, and environmental decision-making. All group members had scientific/engineering backgrounds relevant to aquatic and/or riparian/floodplain resources issues.

- The workshops created a climate for continuing dialogue that ultimately may result in a strategic planning framework for AM of the Ohio River system. Although the workshop discussion was purposely open-ended, the participants may later be involved in developing collaborative long-term agreements, as well as in securing funding to implement an AM program.

13.9.2 Workshop Details and Syntheses of Workshop Discussions

The aquatic resources workshop (encompassing water quality, fish, mussels, and other aquatic life) was convened in Frankfort, Kentucky, on February 11, 2004. It included 14 participants with professional expertise in aquatic resources and was led by the ORMSS CEA team leader. The riparian/floodplain resources workshop followed a similar format and was held in Frankfort on October 20, 2004. It included 22 participants with professional expertise in riparian resources and likewise was led by the ORMSS CEA team leader.

To facilitate the workshop discussions, the CEA planning team developed a few guidelines communicated to each participant prior to the workshop. Secondly, a list of several open-ended questions was developed for discussion at the workshops themselves. Thirdly, workshop discussion was conducted within clearly defined constraints.

13.9.3 Aquatic Sustainability Workshop

The three questions developed to guide the group discussion were:
"What do we want the resource to look like?"
"What needs to happen to attain this vision of the Ohio River?"
"What are possible indicators of environmental sustainability?"

What do we want the resource to look like?

Discussion of the first question resulted in the following description of the resource: "A complex and interconnected system of physical habitat features accompanied by balanced nutrient and energy cycling and minimal amounts of chemical and bacteriological contamination. These habitats would support a diverse, self-sustaining, and resilient aquatic biological community dominated by native species."

The above description was derived from a perspective that connectivity, hydrology, and habitat quality all had two common themes, related in some way to provision of a "complex" set of habitat features "interacting" with each other. The water/sediment factors did not seem to fit with the idea of complexity; rather, they appeared to describe a sense of "balance" wherein individual constituents in the water do not overload the system. These habitat features would maximize opportunities to achieve the composition and functional characteristics associated with healthy biological communities.

What needs to happen to attain this vision of the Ohio River?

In discussing management, the group considered a series of "actions" rather than descriptors of a desirable state. Some of the major actions addressed and discussed in the workshop are listed below:

- Actions related to habitats:

  -Enhance fish passage around or through dams on the mainstem and tributaries.
  -Dismantle tributary dams and restore floodplain functions wherever feasible.
  -Reconnect and restore floodplains on the mainstem and tributaries.
  -Increase seasonal flooding in grasslands, bottomland hardwoods, and other habitats.
  -Maintain or restore tributary deltas and connections between rivers and embayments.
  -Protect existing aquatic habitats, restore lost habitat and diminished resources (woody debris, gravel, shallow nearshore wetlands and embayments, emergent and submergent vegetation, stable shoals, and spawning/nursery areas).
  -Protect or restore riparian habitat diversity, including islands, on the mainstem and tributaries.
  -Allow more natural flows to mimic natural regimes including seasonal and extreme floods and droughts.
  -Address runoff sources affecting aquatic nutrient balance: stormwater, nonpoint, CSOs and SSOs, and agricultural, including concentrated operations.
  -Minimize catastrophic contamination events through reduction of spills, accidents, and improvement of spill response procedures.
  -Continue remediation of CERCLA, brownfields, and other contaminated sites.

- Biological actions:

  -Reintroduce native fauna and expand the range and populations of native fauna from reduced levels.
  -Control exotics, including minimization of existing populations and prevention of new introductions.

- Policy/Procedural Actions:

  -Review and improve the consistency and effectiveness of regulatory actions and enforcement through review of state and federal regulatory processes, use of environmental Best Management Practices (BMPs) and better implementation of CWA.
  -Expand the role of ORSANCO participation on consistency issues, standards and state implementation, designated use attainment/agreement.
  -Conduct economic valuation of watershed functions and benefits.[1]

[1] Suggests an early AM need to assess the extent and value of environmental functions currently provided by the Ohio River and its riparian corridor, plus value of riparian, wetland, and aquatic habitats of tributaries. Helps establish a baseline for estimating environmental function values of restoration efforts.

-Expand the range of policy actions available to increase the public land base[2] or to effect changes in floodplain land use.
-Achieve collaborative arrangements among states, agencies, and landowners to accomplish equitable resources uses – human, recreation, and environmental functions.
-Identify and expand environmentally sound practices at locks, dams, and reservoirs.

- Communications actions:

-Improve/facilitate communications and processes with regulatory entities.
-Increase public awareness/appreciation or aquatic resource issues.
-Document standard operating procedures, EOPs, and BMPs and communicate to concerned institutions.

What are possible indicators of environmental sustainability?

The discussion of candidate indicators generated a broad spectrum of items as well as some initial efforts to organize the items and attendant issues. Some of the major items addressed and discussed in the workshop are listed below:

- Scientific Measures:
  - Baseline water quality and sediments (temporal)
  - Assimilation, analyses of information, and wide dissemination of data
  - Drinking water intake quality
  - Algal and Macroinvertebrate communities

- Composite Indicators of Sustainability:
  - Habitat data – quantity/quality and change over time
  - Designated use attainment
  - Acres of floodplain wetlands
  - Amount of shoreline development
  - People development (demographic shifts?)
  - Recreational pressures
  - Numbers of 404 permits, NPDES permits, and 401 certifications

- Monitoring Needs (related to "What knowledge gaps should be addressed to determine sustainability?")
  - Mussel monitoring
  - Watershed/trib data
  - Consistency with methodology and monitoring
  - Monitoring of larval fish/fish communities – ORFIn
  - Monitor shallow nearshore wetlands/embayments (acres)
  - Riparian vegetation monitoring
  - Genetic monitoring

[2] Land purchases, conservation easements, public/private management agreements, revisions to Conservation Reserve and related programs to maximize areas available for changes in floodplain land use and related habitat restoration efforts.

13.9.4 Riparian Sustainability Workshop

While workshop guidelines were similar to those used for the aquatic exercise, the riparian guidelines reflected some changes resulting from feedback from the original session. Most notably, the discussion questions expanded from the original 3 to the 5 topics summarized here:

1) What do we want the resource to look like?"
2) What must we have to increase riparian sustainability?
3) What specifically needs to be done in riparian habitats in urban areas?
4) What must be measured or monitored to determine sustainability (i.e., indicators)?
5) What actions should be taken or tools used to increase riparian sustainability?

What do we want the resource to look like?

Nearly 40 responses were made to this question, although some responses were similar or overlapping. Initially, all inputs were categorized as relating either to functions of riparian areas or to management opportunities/strategies to protect or improve riparian areas.

The three riparian functions and examples of group responses related to these functions are:

1) Providing diverse habitats – e.g., maintain and create islands, no exotics, revegetate floodplains with native species, diversify wildlife habitat
2) Promoting biogeochemical processes and nutrient cycling – e.g., functioning wetlands, 100+ meter buffer strips to intercept pollution
3) Providing hydrological connections and sediment cycling –e.g., take out or move back levees, mimic natural flows, keep existing islands stable.

Several of the group's responses potentially pertained to all three riparian functions and emphasize the complex, interrelated nature of riparian components. Such responses included restoration of identified degraded sites, floodplain function in whole system context, and presence of floodplain within each pool.

Responses categorized as "management" provided general guidelines for moving Ohio River riparian/floodplain resources in a more sustainable direction. Examples of such responses included allowing minimal floodplain development, acquiring more public lands and refuges, promoting conservation programs on agricultural lands, and creating partnerships and other institutional relationships to improve sustainability.

Combining the group's responses, the following was developed in answer to the question of what the group wants the riparian resource to optimally look like:

> Riparian resources along the Ohio River will form an integrated natural system that attains key functions related to habitat diversity, biogeochemical processes and nutrient cycling, and hydrological connectivity and sediment dynamics.

Such an integrated riparian system would be characterized by functional buffer strips, healthy wetlands, vegetation dominated by diverse native species, and the

enhancement and stabilization of islands. To attain this goal would require limits on floodplain development, more land in public ownership and conservation easements, linkages among fragmented habitats, and more natural flood regimes.

What are the critical needs that must be met to improve riparian sustainability?

Responses to this question included ideas to enhance riparian functions (e.g., increase forest cover) and management strategies (e.g., limit human encroachment through zoning). However, the group acknowledged the necessities of sufficient funding and cohesive institutional management and oversight. These are key elements of an AM program.

What specifically needs to be done in riparian habitats in urban areas?

The responses to this question included physical removal of manmade structures, increased public awareness, and more public ownership and management of urban riparian resources. A strong interest in riverfront projects (parks, multi-purpose facilities, entertainment complexes, etc.) was expressed. Most urban areas either have such projects already or they are in progress. Lack of public understanding and limited education on the benefits of riparian areas hamper improvements to urban riparian areas, but recent public facilities along the riverfront afford opportunities for education and heightened public awareness.

There was a consensus that increased sustainability of urban riparian resources will require careful balancing between land use and recreation use, on the one hand, and maintenance of riparian functions, on the other.

What must be measured or monitored to determine sustainability?

Responses to this questions included acreages of public lands, wetlands, etc., vegetation assessments (e.g., canopy cover, diameter breast height for trees), numbers of certain species, (e.g., nesting birds or amphibians) and various indices of biological assessment (IBIs). A potential tool to evaluate riparian conditions might be developed that is analogous to the Qualitative Habitat Evaluation Index (QHEI) developed for streams. Analyses of trends, riparian stability, and functions were also mentioned as measures of sustainability. Such trend analyses should continue into the future with historic data for key indicators, when available.

What actions should be taken or tools used to increase riparian sustainability?

Responses ranged from implementing specific actions (e.g., developing pool-by-pool masterplans and restoring islands) to actions aimed at establishing working relationships toward common goals (e.g., identification of stakeholders, public commitment) and procuring adequate funding.

Sustainability group members agree that communication is key to attaining goals for Ohio River riparian areas. Not only must public awareness of the importance of riparian areas be heightened, but communications with regulatory agencies and institutions must be strengthened in regard to principles of sustainability, conservation BMPs, and the Corps'

EOPs. An annual or biannual symposium on Ohio River sustainability and AM was suggested as a catalyst/tool to meet communication needs.

13.10 PLANNING FOR ADAPTIVE MANAGEMENT OF THE OHIO RIVER SYSTEM

Developing and implementing an AM program for the Ohio River system could occur over time through the efforts of many stakeholders, but would be unlikely to occur in a focused way unless several key elements formed a framework for action. Those elements include:

- authorization of an agency or organization to initiate an AM program, provide continuity, and ultimately assume responsibility for the program's implementation
- formation of a broadly representative stakeholder group, including members that would identify and conduct monitoring and other tasks and would be capable of recommending management adaptations in response to monitoring outcomes and other data, and
- funding to institute and sustain the program over the long term.

As mentioned previously, the IWG from ORMSS could be an important asset in organizing an AM stakeholders' group which could also include participants from the aquatic and riparian sustainability workshops. Further, a special symposium at forums such as at the ORBCRE could serve as a springboard for the effort.

13.11 CONCLUSIONS

This chapter emphasizes the vital importance of an AM program to continued operation of the Ohio River Navigation System in an environmentally sustainable manner. Further, an AM program and associated monitoring efforts are essential to successful ecosystem restoration of the Ohio River and its watershed. An AM program not only could confirm impacts of restoration efforts, document what works and monitor progress, but also could accomplish restoration objectives with the efficient allocation of available resources. Finally, integrating AM and monitoring into the everyday planning and operation of the Ohio River navigation system could contribute to the Corps continuing to grow as an innovative federal agency in partnership with other entities (private and public) that actively provides leadership and works toward environmental sustainability.

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Exhibit A
PROCEDURE AND METHODS

A.1. OVERVIEW

This chapter describes the procedure and four methods used in conducting this study. The first section summarizes an 11-step procedure, promulgated by the CEQ, for planning and conducting impact studies of cumulative effects. The four methods are addressed in the next four sections of this chapter. The methods that were developed and used include a continuous scoping process; matrices that relate the potential impacts of reasonably foreseeable future actions (RFFAs) to 12 valued environmental components (VECs) and their subcomponents; and an analysis approach for determining the past, present, and future ES conditions of the VECs and subcomponents. The fourth method relates to delineating environmental sustainability (ES) needs; it includes the use of a substantive area expert group to identify ES needs for specific VECs; further, addressing the needs can include mitigation for previous effects (ecological restoration), mitigation for future effects related to RFFAs, monitoring, and an adaptive management strategy integrated across pertinent VECs. Work related to this method has not been initiated; however, due to the fact that completion of this work is beyond the scope of this study, the included information should be viewed as only providing an initial conceptual framework for these efforts. The first method (continuous scoping) relates to all 11 steps in the CEQ procedure, while the RFFA matrices relate to steps 4, 8, and 9. The analyses of ES encompass information and considerations from steps 5 through 9. Lessons learned from the application of the first three methods are described in their respective sections. The method for ES needs relates to steps 10 and 11.

A.2 CEQ PROCEDURE

The CEA study within the ORMSS has been conducted based upon an 11-step methodology promulgated by the Council on Environmental Quality (1997). Steps 1 to 4 relate to scoping, Steps 5 to 7 to describing the affected environment, and, Steps 8 to 11 to determining the environmental consequences. The specific steps and how they were addressed are as follows:

- Step 1 – Identify the significant cumulative effects issues associated with the proposed action and define the assessment goals. This step was based upon the identification of the typical impacts associated with the construction and operation of navigation system locks and dams, and their repair and rehabilitation and periodic maintenance activities. Public scoping meetings were held along with several meetings of a 40-person Interagency Working Group (IWG). The membership of the IWG consisted of representatives from several federal and state agencies responsible for environmental and natural resources management, and three non-governmental organizations. The IWG has participated throughout the CEA study. The initial scoping in Step 1 provided the basis for the identification of

12 VECs of concern. The VECs included aquatic ecological resources (water and sediment quality, mussels, and fish), riparian and floodplain ecological resources (floodplain hydrology, terrestrial habitat, wetlands, islands, and soils and geology), threatened and endangered species (fish, mussels, mammals, birds, and plants), air quality, recreational uses of the River, noise, aesthetics, human health and safety, cultural resources, transportation and traffic, land use, and socioeconomic resources (including environmental justice).

- Step 2 – Establish the geographic scope for the analysis. The scope for the majority of the identified cumulative effects issues and related VECs consisted of the mainstem of the Ohio River along with its 500-year floodplain. Due to data availability on actions, resources, and impacts, the geographic scope often focused on the mainstem and the contiguous counties in the six states along the mainstem.

- Step 3 – Establish the time frame for the analysis. The selected time frame was typically from 1920 to 2060 for most VECs. The earlier date coincides with the initiation of locks and wicket dams on the Ohio River mainstem. The latter date reflects the economic study period for the system investment plan (SIP). One exception for this time frame was the inclusion of information on much earlier cultural properties for the cultural resources VEC.

- Step 4 – Identify other actions affecting the resources, ecosystems, and human communities of concern. As noted in the cumulative effects definition in Chapter 1, "other actions" include past, present, and reasonably foreseeable future actions (RFFAs). To facilitate these identifications and their potential effects, a series of 22 RFFA matrices were developed. The 22 matrices encompassed the 12 VECs and their subcomponents as delineated in Step 1. The RFFAs, which also included similar past and present actions, were defined as:

  Actions identified by analysis of formal plans and proposals by public and private entities that have primary (direct) or secondary (indirect) impacts on VECs associated with the Ohio River. RFFAs also include potential actions that are beyond mere speculation when incorporated in plans or documents by credible private or public entities. RFFAs may also include events forecasted by trends, probable occurrences, policies, regulations, or other credible data that may have bearing on the VECs.

  A total of 87 types of RFFAs were identified and considered in the analyses; the types were divided into six categories: navigation investment actions, other Corps actions, "but for" actions (actions that would not occur "but for" the existence of the navigation system), actions by others, natural disasters, and regulatory environment. Each listed RFFA was characterized in terms of its anticipated time period of occurrence, probability of occurrence, and location on the River. The anticipated effects of each RFFA on each VEC or subcomponent were described in "smart cells" using Microsoft® Excel spreadsheets. Finally, the importance (high, medium, or low) of each RFFA relative to cumulative effects on each VEC or subcomponent was also described in "smart cells"

- Step 5 – Characterize the resources, ecosystems, and human communities identified in scoping in terms of their response to change and capacity to withstand stresses.

This step was based upon an analysis of environmental sustainability (AES) for the pertinent VECs or subcomponents. The AES approach was comprised of four parts: (1) identification of "common effects" on the VEC or subcomponent thereof from the High and Medium importance RFFAs as delineated in the pertinent RFFA matrix (Step 4 above); (2) selection of indicators of ES for the VEC or subcomponent thereof, and their tiered grouping, as appropriate; (3) description of the "connections" between the common effects (and related High and Medium importance RFFAs) and the indicator groups; and (4) assignment of a "bottom line" category to the ES of the VEC or subcomponent, based on considering the past, present and future conditions. The ES categories included "not sustainable", "marginally sustainable", and "sustainable". Specific ES definitions were developed for each VEC or subcomponent (they will be illustrated below for water quality/sediment quality).

- Steps 6 and 7 – Characterize the stresses affecting these resources, ecosystems, and human communities and their relation to regulatory thresholds; and define a baseline condition for the resources, ecosystems, and human communities. These two steps were addressed jointly for each VEC or subcomponent. The approach consisted of identifying historical and current laws, regulations, ordinances, and programs that contain regulatory thresholds and/or policies related to the VEC or subcomponent. Then, historical reference point and trends information, along with current conditions, were summarized for the indicators of ES for the VEC or subcomponent. Numerous information sources were reviewed for Steps 6 and 7. Further, the institutional information and environmental conditions and compliance with regulatory thresholds served as the basis for the categorization of the past and present ES for the VEC or subcomponent.

- Step 8 – Identify the important cause-and-effect relationships between human activities and resources, ecosystems, and human communities. This step was largely accomplished through the development of the RFFA matrices as described in Step 4. Further, peer-reviewed literature, various governmental studies and reports, and impact-study related and resource-management related books were used to more thoroughly document numerous relationships. Attention was also given to various relationships between VECs and subcomponents (e.g., what are the implications of changes in water quality on the populations of mussels in the River?).

- Step 9 – Determine the magnitude and significance of cumulative effects. Due to limited data on specific impacts from various actions, and to the system-wide focus of the CEA study, it has not been possible to quantitatively determine the magnitude of the cumulative effects on the VECs and subcomponents. Rather, a qualitative determination was made based on the AES approach described in Step 5. The significance of the cumulative effects was ascertained via compliance or noncompliance with regulatory thresholds, and the consideration of the connections between common effects and indicators of ES. The assigned categories of ES for the past, present, and future represent the composite significance determination for the cumulative effects on each VEC or subcomponent.

- Step 10 – Modify or add alternatives to avoid, minimize, or mitigate significant cumulative effects. This step has been addressed via the identification of generic

mitigation measures for many of the analyzed actions, with particular attention being given to such measures for navigation investment actions by the Corps. In addition, various regulatory programs that have facilitated, or are expected to emphasize, generic mitigation measures for numerous actions have also been identified and incorporated in the analysis. Further, the fourth methods described in this chapter delineates a process used to identify various mitigation and other ES needs for aquatic ecological and riparian/floodplain ecological resources.

- Step 11 – Monitor the cumulative effects of the selected alternative and adapt management. This step has been addressed in a systematic manner for each VEC and subcomponent. The key criteria that are being used to "trigger" Step 11 are the past, present, and future ES categories for the VECs and subcomponents. If the VEC or subcomponent is currently "sustainable", and this is expected to continue into the future, only targeted additional monitoring over that currently being done is recommended, and no specific adaptive management strategy will be developed. For VECs or subcomponents that are currently categorized as "not sustainable", or "marginally sustainable", specific collaborate monitoring will be recommended along with an appropriate adaptive management strategy.

An early activity in this study involved the development of detailed work plans for each of the 12 VECs, including their respective subcomponents. The 11 steps of the CEQ procedure served as the conceptual basis for each work plan. The generic topics addressed in each work plan included:

- Definition of the VEC and its subcomponents
- Information sources related to the VEC and its subcomponents
- Overview of work plan (related to the CEQ's 11-step procedure)
- Phase 1: Identify "scope" of the VEC study
  - -- CEQ Steps 1 and 4. Identify the typical impact issues related to direct actions by the Corps, and identify other actions that also impact the same VEC and its subcomponents
  - -- CEQ Step 2. Identify the geographic boundaries
  - -- CEQ Step 3. Select the time frame
  - -- Select indicators for the VEC and its subcomponents
  - -- CEQ Step 8. Identify cause and effect relationships between past, present, and RFFAs and their adverse effects on the VEC and its subcomponents
  - -- Identify management goals for the VEC and its subcomponents and who is responsible
- Phase 2: Describe historical baseline and current conditions

-- CEQ Step 7. Develop anecdotal and institutional information on the historical baseline

-- CEQ Steps 5 and 6. Characterize the potentially affected VEC and its subcomponents in terms of their response to change and capacity to withstand adverse impacts, and characterize current (existing) stresses and their relationship to regulatory thresholds

-- Consider the identification of special stressed zones or protection zones within the geographic boundaries

-- Delineate criteria to consider in establishing the significance of particular cumulative effects

- Phase 3: Determine magnitude and significance of cumulative effects on the VEC and its subcomponents

  -- CEQ Step 9. Determine the magnitude and significance of cumulative effects on selected indicators of the VEC and its components (included consideration of "best current practice" methods for qualitatively or quantitatively expressing the cumulative effects)

  -- List the significant cumulative effects and describe the bases for their classification

- Phase 4: Develop mitigation/monitoring programs (as appropriate)

  -- CEQ Step 10. Modify or add alternatives to avoid, minimize, or mitigate significant cumulative adverse effects on selected indicators of the VEC and its subcomponents

  -- CEQ Step 11. Monitor the significant cumulative effects on the VEC and its subcomponents, and adapt management as appropriate

- Phase 5: Prepare specific outline and chapter on the process, and findings for the VEC and its subcomponents

- Appendices of policy and related information (as appropriate) from the Corps' Planning Guidance Notebook (ER 1105-2-100).

The emphasis in the assemblage of pertinent information was on the preparation of chapters that coincided with individual or combined VECs, or their subcomponents. The work plans provided a framework for both the assemblage and analysis of the pertinent information. The typical topical contents of these substantive chapters included:

- Definition of VEC and its Subcomponents

- Objectives and Scope of the VEC Study

- Issues from Scoping
- Indicators of Environmental Sustainability
- Laws, Regulations, Ordinances, and Programs
- Past to Current Baseline Conditions for the VEC and its Subcomponents
- Special Information Related to the Ohio River
- Interactions with Other VECs
- Relevant Actions Affecting the VEC and its Subcomponents
- Cumulative Effects and Environmental Sustainability
- Summary and Conclusions
- References

As the CEA study progressed, it was soon realized that research studies, surveys, or data gathering efforts would be necessary. Following is a list of these activities conducted to support this CEA study:

- Survey of lipid and fatty acid composition in paddlefish, white bass, and sauger collected from six navigation pools (Hannibal, Belleville, Greenup, Meldahl, Cannelton, and Smithland) -- the results are noted in Chapter 6. Reference -- Wells, M. J., "Ohio River Mainstem Systems Study - Fatty Acid Investigation", draft, September 30, 2003, Tennessee Technological University, Cookeville, Tennessee.

- Study of various engineering and hydraulic factors related to Ohio River locks and dams, along with fish swimming velocities of 44 target species, to ascertain upstream fish passage opportunities at the mainstem dams -- the results are summarized in Chapter 6. Reference -- Knights, B. C., J. H. Wlosinski, J. A. Kalas, and S. W. Bailey, "Upstream Fish Passage Opportunities at Ohio River Mainstem Dams", 2003, U. S. Geological Survey, Upper Midwest Environmental Sciences Center, La Cross, Wisconsin.

- Study of winter habitat types used by fishes in the Smithland and Belleville navigation pools, and comparison of the results between the downstream and upstream pools -- the results are summarized in Chapter 6. Reference -- Garvey, J. E., S. Welsh and K. J. Hartman, "Winter Habitat Use by Fishes in Smithland Pool and Belleville Pool, Ohio River", 2003, Prepared by the Fisheries and Illinois Aquaculture Center, USGS, and WV Cooperative Fish and Wildlife Research Unit, Southern Illinois University, Carbondale, Illinois.

- Survey of glochidial infestation on Ohio River fish species -- the results are noted in Chapter 6. Reference -- O'Bara, C. J., "Presence of Glochidial Infestation on Ohio River Species", draft, March, 2004, West Virginia Division of Natural Resources, Parkersburg, West Virginia.

- Survey of fish community structures with lock chambers in relation to tailwater fish communities, and short-term movement patterns of targeted species at the Winfield locks and dam on the Kanawha River -- the results are noted in Chapter 6. Reference -- O'Bara, C. J., "Fish Passage: Direct Observations", draft, March, 2004, West Virginia Division of Natural Resources, Parkersburg, West Virginia.

- Study of fish movement in the middle Ohio River region based on fish tagging and tag return data -- the results are summarized in Chapter 6. Reference -- O'Bara, C. J., "Fish Tagging and Recovery", draft, March, 2004, West Virginia Division of Natural Resources, Parkersburg, West Virginia.

- Description and results of creel surveys (recreational angling) conducted in 2002 in the tailwaters of upper River locks and dams -- the results are summarized in Chapter 4. Reference -- O'Bara, C. J., "Recreational Fishery Survey", draft, March, 2004, West Virginia Division of Natural Resources, Parkersburg, West Virginia.

- Composite results of fish research -- the findings are summarized in Chapter 6. Reference -- O'Bara, C. J., "Fish Passage Issues Associated with Ohio River High Lift Dams", draft, April, 2004, West Virginia Division of Natural Resources, Parkersburg, West Virginia.

- Compilation of basic literature and historical data on mussel species in the navigation pools of the Ohio River mainstem -- the findings are summarized in Chapter 5 -- Reference -- Watters, G. T., T. Cavender, C. Myers, M. Kibbey, V. Gordon, B. Pittinger and T. Pohlman, "Fish Passage Study, Product 3: Distribution of Mussels and Fish within the Ohio River (including Ohio River Mussel Database CD)", 2003, Ohio State University, Columbus, Ohio.

- Review and analysis of the Corps ' statutory authorities, policies, regulations and guidance for mitigation of historical environmental damages from Corps projects and actions by others, and for mitigation of proposed Corps projects, plans, and/or programs -- the results are summarized in this chapter. Reference -- Canter, L. W., "Identification and Analyses of U. S. Army Corps of Engineers Policies and Procedures Related to Retrospective Mitigation (Ecosystem Restoration) and Prospective Mitigation", September, 2003, Horseshoe Bay, Texas.

- Hydrogeomorphological survey of islands in the Ohio River mainstem -- the results are noted in Chapter 7, Reference -- Spoor, M., Huntington District, U. S. Army Corps of Engineers.

- Collection of data on bottom substrates and bathymetry for navigation pools in the middle to upper Ohio River mainstem -- the results will be used in NAVPAT

modeling, and the findings will be incorporated in Chapter 6. Reference -- Siemsen, T., Louisville District, U. S. Army Corps of Engineers.

- Several databases have been developed from these studies; they include a spatial database for historic mussel and fish distribution, fish tagging studies, and angler use surveys. The NAVPAT field data could also be placed in a database. Each of these databases are intended to be made available in a user-friendly CD.

- Finally, although not a part of this CEA study, the Corps is preparing a Section 7 biological assessment related to navigation system operational practices and effects on threatened or endangered plant and animal species within or nearby the Ohio River mainstem.

A.3 CONTINUOUS SCOPING PROCESS

The use of a targeted scoping process is critical to the successful planning and completion of time-efficient and cost-effective CEA studies for programmatic-level plans. Accordingly, the components of the scoping process for the CEA study and associated PEIS for the Ohio River navigation SIP are described herein. Four subsections are included. Fundamental information on the principles and practices related to the scoping process in the first subsection. The second subsection highlights six components of the utilized scoping process. The third subsection illustrates how information from the process was utilized in planning and conducting the CEA study. Finally, the fourth subsection enumerates the conclusions and lessons learned regarding cumulative effects scoping for this SIP/PEIS.

A.3.1 Background on Scoping

Scoping refers to an early and open process for determining the scope of the impact study and the significant issues to be addressed in an EIS or PEIS. This process was incorporated in the NEPA regulations promulgated by the CEQ in 1978 (Council on Environmental Quality, 1978). "Early" suggests that the process will occur during the initial stages of planning a PEIS, although scoping can continue throughout a study, particularly for programmatic-level studies such as this navigation system study that incorporates increased emphasis on themes such as CEA and environmental sustainability (U.S. Army Corps of Engineers, 2002 and 2003). "Open" denotes that the process provides the opportunity for participation by affected federal agencies, state and local governments, Indian tribes, environmental nongovernmental organizations (ENGOs), development entities, and various other publics (stakeholder groups and individuals).

The scope of the study is related to the range of actions, alternatives, and impacts to be addressed in the PEIS (Council on Environmental Quality, 1978). Other than unconnected single actions, the range of actions can include "connected actions" to the original proposal, and "cumulative actions" and "similar actions" which can affect common environmental features. The range of alternatives are to include the "no action" alternative (this could be a continuation of current practices or a no project option), other reasonable courses of action to meet the identified needs, and the proposed action with add-on mitigation measures not included in the original concept and design. The range of impacts should include the direct and indirect impacts of the proposed action and

alternatives, as well as the cumulative impacts of past, present, and reasonably foreseeable future actions on common resources, ecosystems, and human communities.

Generic objectives for the scoping process include (Council on Environmental Quality, 1981): (1) to identify the affected public and agency concerns; (2) to facilitate an efficient PEIS preparation process, through assembling the cooperating and pertinent agencies, assigning writing tasks, ascertaining all the related permits and reviews that must be scheduled concurrently, and setting time or page limits; (3) to define the issues and alternatives that will be examined in detail in the PEIS while simultaneously devoting less attention and time to issues which cause no major concern; and (4) to save time in the overall NEPA process by helping to ensure that the draft PEIS adequately addresses relevant issues, reducing the possibility that new comments will cause a statement to be rewritten or supplemented. A thorough scoping process provides the necessary basis for allocation of time and funding to address truly important resource issues. These generic objectives are being accomplished via the multi-component scoping process being used in this CEA study and the related SIP/PEIS.

An important principle related to the scoping process is that it should be uniquely designed for each impact study. The process itself can incorporate multiple features such as conducting a series of scoping meetings, telephonic and/or e-mail surveys of the perspectives of various agency and public stakeholders regarding the necessary scope, soliciting written comments from various stakeholders regarding the scope and significant issues to be addressed, and completing research studies and literature-based policy/scientific reports on potentially affected resources, ecosystems, habitats, and protected species. Each of these features has been incorporated in the continuing scoping process for this CEA study on the navigation SIP/PEIS.

Another approach that can be used in the scoping process is for the lead agency (i.e., the Corps) to identify and formally establish one or more cooperating agencies relative to preparing the SIP/PEIS. Cooperating agencies may include other federal agencies that have "jurisdiction by law" or "special expertise" relative to the potential impact issues to be addressed. Duties of the lead agency in this matter include (Council on Environmental Quality, 1978): (1) requesting the participation of each cooperating agency at the earliest possible time; (2) using the environmental analyses and proposals of cooperating agencies with jurisdiction by law or special expertise, to the maximum extent possible consistent with its responsibility as lead agency; and (3) meeting with cooperating agencies at their request. The duties of cooperating agencies include (Council on Environmental Quality, 1978): (1) participating in the scoping process; (2) assuming on request of the lead agency responsibility for developing information and preparing environmental analyses, including portions of the PEIS concerning which the cooperating agency has special expertise; (3) making available staff support at the lead agency's request to enhance the latter's interdisciplinary capability; and (4) normally using its own funds. However, the lead agency shall, to the extent monetary resources are available, fund those major activities or analyses it requests from cooperating agencies.

The Corps considered inviting one to several cooperating agencies for the environmental studies conducted under the ORMSS; however, an alternate strategy that involved the establishment of an Interagency Working Group (IWG) was utilized. The IWG includes several members from federal agencies that could have been invited to be

cooperating agencies. The specific involvements of the IWG in this case study are described in the next two subsections.

Specific scoping-related duties of the lead agency, that the Corps has fulfilled, include (Council on Environmental Quality, 1978):

- Invite the participation of affected federal, state, and local agencies, any affected Indian tribe, the proponent of the action, and other interested persons (including those who might not be in accord with the action on environmental grounds).

- Determine the scope and the significant issues to be analyzed in depth in the PEIS.

- Identify and eliminate from detailed study the issues which are not significant or which have been covered by prior environmental review, narrowing the discussion of these issues in the PEIS to a brief presentation of why they will not have a significant effect on the human environment or providing a reference to their coverage elsewhere.

- Indicate any public EAs and other EISs that are being, or will be, prepared that are related to but are not part of the scope of the PEIS under consideration.

- Identify other environmental review and consultation requirements so the lead agency may prepare other required analyses and studies concurrently with, and integrated with, the PEIS.

- Indicate the relationship between the timing of the preparation of environmental analyses and the agency's tentative planning and decision making schedule.

The most widely used approach in the scoping process involves public and agency-specific meetings with interested and/or pertinent stakeholders. Multiple benefits can accrue from such meetings and the related information exchange. For example, some of the best effects of the scoping process stem from the fact that all stakeholders have the opportunity to meet one another and to listen to the concerns of the others. If there is any possibility that an early resolution of underlying conflicts may be achieved, this can be enhanced by the development of personal and working relationships among the stakeholders. Further, stakeholders typically appreciate the opportunity of participating in the planning and review process (Council on Environmental Quality, 1981). The key person in various types of face-to-face meetings is the moderator (or impact study team leader) from the lead agency. The person should be focused on both communicating information about the study and soliciting related information and viewpoints from the participants.

Another feature of the scoping process is that the lead agency must consider and evaluate various inputs regarding the study scope and significant issues, and then make determinations of what will be addressed in the study and what will be eliminated or set aside for future consideration. The process of selection, elimination, or set-aside should be carefully documented, perhaps within a "scoping report" that could be included as an Exhibit in the Cumulative Effects Report or the Programmatic Environmental Impact Statement. The more extensive scoping report could be used to develop a summary of the

scoping meetings that could be provided, via traditional mail or e-mail, to all of the participants. This documentation and dissemination was incorporated in the process for this case study, with the resultant reports included in Exhibit A.

While the scoping process is often described in a step-wise manner, in reality, scoping is an iterative process. Throughout all phases of a study, previously unidentified concerns are discovered or policies/guidance are changed. It is essential that study teams recognize these events and factor them back through the process to ensure that the final document reflects the most up-to-date information. This was done in this case.

Finally, many practitioners consider the scoping process to be the most critical phase in the preparation of a PEIS. Examples of the potential benefits of a successful process include the possibility that real problems are identified early and properly studied; that issues that are of no concern do not consume time and effort; that major potential conflicts can be addressed up-front and potentially resolved; that the draft PEIS is balanced and thorough; and that the delays occasioned by re-doing an inadequate draft are avoided (Council on Environmental Quality, 1978).

A.3.2 Components of the Scoping Process

The scoping process for the CEA and the SIP/PEIS for the Ohio River navigation study was characterized by multiple components, with several extending from the early planning stage to the completion of the SIP/PEIS. **Table A-1** provides a brief synopsis of the six components and their key functions in relation to the entire scoping process. Each component is described in the following portions of this subsection.

TABLE A-1
Components of the Scoping Process

Component	Key Functions
Central Planning Team (CPT)	Provided leadership to the entire scoping process; including educational features related to CEA; interactions with the OB and IWG; development of VECs, RFFAs, methods, and AES; and analyses of received information.
Steering Committee --- Oversight Board (OB)	Provided policy advice and overall approvals for scheduling and budgetary matters for the entire ORMSS.
Interagency Working Group --- (IWG)	Provided scientific and/or policy advice to the CPT; aided in identifying research needs; participated in the completion of RFFA matrices, the identification of indicators for AES, and the delineation of ES needs; and reviewed various study documents.
Scoping Meetings --- Agencies and General Public	Provided input on the scope of the CEA study and related SIP/PEIS, including the identification of cumulative effects concerns and contributory actions to these concerns.
Questionnaires	Provided input on past actions and effects on aquatic and riparian ecological resources, the relative importance of the 12 VECs, and future concerns and management approaches.
Informational Website	Contained information on the ORMSS, public meetings, and the results of the scoping meetings; used by individuals to request further information on the issues of concern.
Notes: CEA = cumulative effects assessment, VECs = valued environmental components RFFAs = reasonably foreseeable future actions, AES = analysis of environmental sustainability,	

ORMSS = Ohio River Mainstem Systems Study, SIP/PEIS = system investment plan and programmatic environmental impact statement

A.3.2.1 Central Planning Team

The Central Planning Team (CPT) was comprised of seven members, including three persons from the Corps and four persons from an environmental consulting firm. The disciplinary backgrounds include three biologists, one environmental engineer, one environmental scientist, one landscape architect, and one political scientist/planner. Regarding their experience with impact studies, one CPT member has over 30 years experience, three have from 15 to 25 years experience, and three have about 5 years experience each.

The CPT met every 2 to 3 months for the purposes of determining the timing and budgetary status of work-in-progress, conducting joint planning for specific future work elements and the overall connections between the CEA study and the SIP/PEIS, and jointly reviewing draft chapters, sections within chapters, and appendices. The need to develop a method or process for completing a task or for transitioning from one task to another was frequently identified, and such tools or methods were proposed, developed, tested, and refined during the meetings. These periodic meetings have proven to be invaluable due to the broad nature of the SIP/PEIS, and the use of CEA as a means of integrating the effects of multiple actions on environmental features within the study area.

The CPT has provided leadership related to other components of the scoping process, as well as the leadership for continuing efforts. More specifically, the CPT has:

- Developed an overall CEA and SIP/PEIS study plan based upon an 11-step CEA procedure described by the CEQ (Council on Environmental Quality, 1997) and the requirements for PEISs in the NEPA regulations (Council on Environmental Quality, 1978).

- Conducted several information gathering activities related to the history of mainstem developments and aquatic and riparian resources of the Ohio River; such activities included Internet surveys and traditional literature searches, telephonic and e-mail requests for information, reviews of numerous Corps reports related to the environmental effects of locks and dams and lock expansions, and reviews of research reports and surveys of natural and environmental resources prepared by others.

- Identified 12 Valued Environmental Components (VECs) within the study area that were subject to cumulative effects, and prepared work plans for each VEC based upon the above-noted 11-step CEA procedure.

- Planned the agendas for periodic meetings with the IWG, and provided study updates and educational components for these meetings.

- Planned and conducted 12 scoping meetings at 6 locations along the Ohio River mainstem, and prepared a summary report (see Exhibit A).

- Developed a questionnaire for solicitation of input on the overall study and the relative importance of the 12 VECs. The questionnaire was used in the scoping meetings and made available on an ORMSS website. Further, the CPT prepared a summary of the questionnaire results (see Exhibit A).

- Developed and periodically updated an overall ORMSS website for the purpose of providing summary information on the features of the study and related presentations.

- Prepared draft chapters, sections, and appendices for the CEA study that have been reviewed by the IWG. Examples of such products that have been distributed include the summary report of public scoping meeting, an Exhibit on the development and completion of RFFA matrices, and chapters on the VECs or their subcomponents.

- Conducted "situational awareness" reviews of the CEQ's handbook on conducting CEAs (Council on Environmental Quality, 1997), a related large-scale navigation study on the Upper Mississippi River System (including a review of that study by the National Academy of Science and subsequent guidance from Corps Headquarters), and the U.S. Army Chief of Engineers' (Corps) Environmental Operating Principles. These reviews provided a useful context for this case study.

A.3.2.2 Steering Committee

A steering committee can provide valuable inputs during the conduct of programmatic impact studies. For the ORMSS, the steering committee was the Oversight Board (OB), which is a 14-person group comprised of Corps management-level professionals from the pertinent geographical Division and three involved Districts. The OB meets quarterly and conducts monthly teleconferences. It provides leadership direction relative to the overall ORMSS; such direction includes scheduling, budgetary approvals and adjustments, reviews of work-in-progress, and periodic policy decisions relative to topical issues and related intra- and inter-agency coordination and collaboration. Two of the Corps members of the CPT routinely interact with the OB.

A.3.2.3 Interagency Working Group

The IWG consists of approximately 40 members representing federal and state agencies with responsibilities for environmental management, as well as several ENGOs. Six members were from the U.S. Fish and Wildlife Service, with one serving as the coordinator for the USFWS group; two were from the U.S. Geological Survey; and one was from the U.S. Environmental Protection Agency. In addition, the Ohio River Valley Sanitation Commission (ORSANCO), a federally chartered compact among several states in the Ohio River drainage, had two representatives on the group. Members from ENGOs include one person from the Sierra Club, one from the Ohio River Foundation, and two from The Nature Conservancy. The remaining members are from natural resources or environmental management agencies in the six states bordering the Ohio River. The IWG had two to three meetings annually with the CPT. These one-day joint meetings included information dissemination and updates related to the status of the CEA study, status reports on specific research projects, and working sessions on integrative topics such as impact

matrices for RFFAs, and indicators and a process for analyses of environmental sustainability (AES).

More specifically, the IWG has fulfilled the following purposes:

- Aided in identifying key issues and cumulative effects that should be addressed in the CEA study.

- Assisted the CPT in delineating and prioritizing key research needs relative to environmental issues and natural resources. Examples of completed research include fish passage studies at selected locks, determination of winter habitat requirements for selected fish species, and surveys of freshwater mussel populations at various river locations. In addition, the IWG has reviewed the completed research reports.

- Participated in the completion of RFFA matrices for VECs and their subcomponents related to aquatic ecological resources, floodplain/riparian ecological resources, and threatened/endangered/protected species.

- Reviewed work plans for addressing cumulative effects on the 12 VECs and their subcomponents; in addition, reviewed the identified methods and procedures relative to "best practice tools" for the specific issues and cumulative effects to be addressed. It should be noted that "best practice tools" infer both scientific validity and cost-effectiveness relative to their application.

- Conducted systematic reviews of draft chapters and appendices for the CEA study report and the SIP/PEIS.

- Provided periodic and continuing scientific information on emerging issues; examples include the incorporation of the environmental sustainability analyses and the need to consider nonstructural measures for navigation traffic management, along with proactive repair and rehabilitation of existing locks and dams, and lock extensions.

- Participated in the planning and implementation of a coordinated and collaborative long-term strategy for environmental monitoring and adaptive environmental management for the aquatic and floodplain/riparian ecological resources within and along the Ohio River mainstem. In fact, the IWG could become part of a long-term decisionmaking structure and process related to enhancing the environmental sustainability of key resources.

In summary regarding the OB and IWG, both provide the CPT with valuable scientific information and advice. Further, mutual education and continuing networking is occurring among the OB and CPT, and the IWG and CPT. The "buy-in" of various governmental agencies and ENGOs to the study process was achieved via a healthy dialogue. Negative perceptions related to the role of committees are typically associated with the logistics and costs regarding meetings, the roles and limits of such committees in decisionmaking processes, and the creation of unmet expectations for all involved persons. However, these negative perceptions were greatly exceeded by the benefits noted above.

As a result, the two committees in this study facilitated more time-efficient and cost-effective impact studies related to the ORMSS.

A.3.2.4 Scoping Meetings

Twelve public scoping meetings were held during the summer of 2001. Two meetings each were held in smaller cities in the six contiguous states to the Ohio River (Metropolis, Illinois; Evansville, Indiana; Parkersburg, West Virginia; Monaca, Pennsylvania; Covington, Kentucky; and Portsmouth, Ohio). At each location, an afternoon meeting was held with representatives of governmental agencies, and an evening session was held for the general public. Each of the meetings was announced via a notice in the Federal Register, press releases to local newspapers, mailings to all addresses on the ORMSS mailing list, and legal ads in major regional newspapers. More than 50% of the attendees at the afternoon sessions were from federal and state resource or regulatory agencies, with the remainder from public agencies and some business groups. Approximately 50% of the evening attendees were interested citizens, with the other 50% being from businesses, the navigation industry, environmental groups, the media, and governmental agencies. Some elected officials attended either afternoon or evening sessions.

A brochure entitled "Ohio River Mainstem Systems Study – Cumulative Effects Assessment" was distributed to the attendees at the scoping meetings, and also to persons requesting information via telephonic, written, or e-mail contacts. The brochure included brief descriptions of the navigation system issues, the goals of the CEA study, the 12 VECs, the role of public involvement and participation in the study, and the overall ORMSS program (see Exhibit A).

The format of each of the 12 meetings included a brief (5 minutes) presentation on the key elements of the ORMSS, a review (10 minutes) of several navigation system needs and the key components of the ORNIM, a brief synopsis (5 minutes) on the features of a SIP/PEIS and the relationship of the CEA study to the SIP/PEIS, and a focused educational tutorial (15 minutes) on the principles and steps associated with conducting a CEA study. These presentations were followed by a moderated question-and-answer session that typically listed for about one hour.

A composite "Scoping Comments Matrix" was compiled to summarize all of the received comments and issues identified from the meetings. The comments were grouped into 26 categories as illustrated in **Table A-2** (in many cases the same comment was made multiple times, and this was so noted in the matrix). The Scoping Comments Matrix is in Exhibit A. Its structure consisted of the left column comprised of the 26 categories in Table 2, with as many rows as needed for the individual comments and issues associated with each category. Twelve columns in the matrix related to the 12 VECs, with three additional columns associated with an authorized but unfunded Ecosystem Restoration Program (ERP), the overall ORMSS, and general concerns. Each comment row was connected, as appropriate, to the relevant columns. The final column in the matrix was entitled "Action", and a brief statement was included as to the disposition of each comment relative to the CEA study. The following "actions" were typically noted:

- Comment noted (no further action needed at this time)

- Currently being addressed
- Will be addressed (later in the CEA study)
- Will be addressed for a specific VEC (later in the CEA study)
- Addressed in the (scoping) meeting
- Comment will be forwarded to the ERP team

To provide feedback to the participants on the results of the scoping meetings, a brief summary report, along with the Scoping Comments Matrix, was provided to each person, either by e-mail or traditional mail (see Exhibit B). These same items were also included in the ORMSS website.

TABLE A-2
Topical Categorization of Comments and Issues from Scoping Meetings

Ohio River Mainstem Systems Study (ORMSS)
Cumulative effects assessment (CEA)
Baseline conditions
Barge operations
Navigation infrastructure
Water quality
Groundwater
Sedimentation
Dredging
Bank/shoreline instability
Pool elevations
Land use
Recreation/fishing
Fish and wildlife
Threatened and endangered species
Exotic/invasive species
Ohio River islands
Cultural resources
Trash (solid waste)
Aesthetics
Private property
Energy
Environmental regulations
Intermodal transportation facilities
Ecosystem Restoration Program (ERP)

Other questions/concerns

Several lessons were learned regarding scoping meeting successes and areas needing improvement. Successes were a result of: (1) the thorough planning for the meetings by the CPT; (2) the technical preparation for the meetings; (3) the educational focus of the organized presentations at the meetings; (4) the exchange of information which occurred during the question-and-answer sessions; (5) the knowledge, experience, and communication skills of the moderator for the meetings; and (6) the timely feedback of summary information to the participants. The areas needing improvement for future public meetings on the SIP/PEIS relate to meeting announcements and locations. Specifically, a comprehensive approach is needed to identify organizations and pertinent mailing lists for inviting potentially interested groups and persons to the meetings. Second, all involved persons from the lead agency (beyond those on the CPT) need to be briefed so that they will clearly understand the purposes of the meetings and communicate this information, as appropriate, to the media and in response to verbal or written questions. Another need is to develop a mechanism (possibly through the agency's Public Affairs Office) to thoroughly review recent information from newspapers, radio, and television announcements, particularly for erroneous information that may have been disseminated, and convey that information to the moderator prior to the meeting. It is essential that any misleading perceptions be corrected at the beginning of the scoping meeting in order to keep to the primary topic. Finally, it would be desirable to have a member of the CPT actually visit all potential meeting locations prior to their selection; this would enable the independent verification of room size and available equipment and administrative support.

A.3.2.5 Questionnaire

The questionnaire used in the public scoping meetings and to fulfill information requests is shown in **Table A-3**. The 8 questions are structured to focus on several of the 11 steps in the CEQ's CEA procedure (Council on Environmental Quality, 1997). The 11 steps are identified in the next section; with the questions related to them in the following manner: Question 1 – Steps 4, 5, and 7; Question 2 – Steps 4 and 6; Question 3 – Steps 4 and 11; Question 4 – Steps 1, 5, 6, 7, 8, and 9; Question 5 – Steps 1 and 9; Question 6 – Step 4; Question 7 – Steps 10 and 11; and Question 8 – all 11 steps.

TABLE A-3
Questions in the Scoping Questionnaire

1.	What do you think is the most important change associated with the Ohio River over the past 20 to 25 years; and do you consider this change to be beneficial or detrimental?
2.	What do you like best about the current conditions for the Ohio River; and what do you like the least?
3.	What change would you most like to see for the Ohio River over the next 50 to 60 years; and what change would you least like to see over the same time period?
4.	Please assign an importance number to the following Environmental Resources identified for the Cumulative Effects Assessment (CEA) study of the Ohio River. Write a "3" in parentheses for those Environmental Resources you think have the highest importance, 2 for those with moderate importance, and 1 for those with the lowest importance:

( ) Aquatic ecological resources (includes biological resources such as fish, mussels, waterbirds, etc.; and water quality and sediments)

( ) Air quality

( ) Riparian/floodplain ecological resources (includes terrestrial habitats, islands, wetlands, soils and geology, and floodplain hydrology)

( ) Threatened, endangered, and other protected species

( ) Aesthetic resources (includes visual quality and scenic resources

( ) Noise

( ) Human health and safety (includes hazardous waste sites and chemical spills)

( ) Land use (includes changes from projected developments)

( ) Transportation and traffic (includes changes in shipping modes and commodities shipped)

( ) Socioeconomic resources (includes population changes and environmental justice)

( ) Cultural resources (includes historical and archeological resources)

( ) Recreation (includes river-based activities)

5. For those Environmental Resources you think are most important; please identify your reasons why.

.

6. For those Environmental Resources you think are most important list the past and current actions (by any governmental entities or the private sector) which have contributed to cumulative effects concerns for the respective Environmental Resources.

7. What strategies should be considered to more effectively manage future cumulative effects concerns for the Environmental Resources you think are most important?

8. List any other comments you have regarding cumulative effects and the CEA study within the ORMSS being planned by the U.S. Army Corps of Engineers.

The written comments on Questions 1 through 3 and 5 through 8 were particularly helpful in identifying cumulative effects and related concerns. Question 4 involved rating the importance of the 12 VECs and their subcomponents. Based upon the responses, two importance groupings for the VECs were identified as shown in **Table A-4**.

A.3.2.6 ORMSS Website

An Internet website for the ORMSS was maintained and periodically updated by the Louisville District of the Corps. The website address is www.lrl.usace.army.mil.ormss/ As of August, 2003, it contained a fact sheet on the ORMSS, 13 frequently asked questions related to the navigation economics study and the ORNIM, an announcement of the CEA public scoping meetings, and a summary of the meetings and received comments. In addition, the 8-question CEA questionnaire is also included.

TABLE A-4
Importance Groupings and Disposition for the 12 VECs

Importance Grouping	VECs and Associated Subcomponents	
Higher	• Aquatic ecological resources -- separate and detailed chapters prepared for the fish, mussels, and water quality/sediment quality subcomponents • Riparian/floodplain ecological resources (includes terrestrial habitats, islands, wetlands, soils and geology, and floodplain hydrology) – detailed chapter prepared • Threatened, endangered, and other protected species – addressed in the fish, mussels, and riparian/floodplain chapters • Human health and safety (includes hazardous waste sites and chemical spills) – detailed chapter prepared • Recreation (includes river-based activities) – detailed chapter prepared • Transportation and traffic (includes changes in shipping modes and commodities shipped) – detailed chapter prepared	
Lower	Individual chapters prepared for: • Socioeconomic resources (includes population changes and environmental justice) • Air quality • Cultural resources (includes historical and archeological resources)	Other: • Land use (includes changes from projected developments) – exhibit prepared • Noise – addressed in the human health and safety chapter • Aesthetic resources (includes visual quality and scenic resources) – included in recreation chapter

A.3.3 Integration of Scoping Process Information

Information from the various components of the scoping process has been integrated throughout the planning and conduction of the CEA study. The study itself is based upon the 11-step procedure promulgated by the CEQ, and as described earlier (Council on Environmental Quality, 1997). The scoping process itself was used in relation to all 11 steps. The integration of scoping process information within the 11 steps is described below. The CPT has provided the leadership for the approach for each step.

- Step 1 – Identify the significant cumulative effects issues associated with the proposed action and define the assessment goals. Public scoping meetings, along with the joint meetings with the IWG, and work by the CPT, provided the basis for the identification and prioritization of the 12 VECs of concern (see Table 4).

- Step 2 – Establish the geographic scope for the analysis. The approach for establishing the geographic boundaries for individual VECs was discussed with the IWG and OB. Further, it was recognized that it is very important to maintain a

degree of flexibility in establishing geographic boundaries. No single type of boundary definition (e.g., political, watershed, etc.) works well for every resource, ecosystem, and human community. Therefore, the delineation of general boundaries must be allowed to be adjusted somewhat to fit the nature of a particular VEC.

- Step 3 – Establish the time frame for the analysis. Again, the approach for establishing the temporal boundaries was discussed with the IWG and OB. Just as with establishing geographic boundaries, general temporal boundaries must be amenable to adjustments. Factors such as availability and quality of historical data may limit quantitative analyses, and use of anecdotal information may become a necessity for certain VECs.

- Step 4 – Identify other actions affecting the resources, ecosystems, and human communities of concern. As noted in the cumulative effects definition above, "other actions" include past, present, and reasonably foreseeable future actions (RFFAs). Information for many of the types of RFFAs was derived from the IWG, the scoping meetings, the questionnaire, and usage of the ORMSS website. As noted earlier, the anticipated effects of each RFFA on each VEC or subcomponent were described in "smart cells" using Microsoft® Excel spreadsheets. Finally, the importance (high, medium, or low) of each RFFA relative to cumulative effects on each VEC or subcomponent was also described in "smart cells". The IWG participated with the CPT in the completion of several of 22 RFFA matrices.

- Step 5 – Characterize the resources, ecosystems, and human communities identified in scoping in terms of their response to change and capacity to withstand stresses. This step was based upon an analysis of environmental sustainability (AES) for the pertinent VECs or subcomponents. The AES is the third method described herein. The IWG participated with the CPT in the development of this approach.

- Steps 6 and 7 – Characterize the stresses affecting these resources, ecosystems, and human communities and their relation to regulatory thresholds; and define a baseline condition for the resources, ecosystems, and human communities. Information received from the IWG, scoping meetings, and the questionnaire, relative to institutional requirements, historical and current conditions, and appropriate regulatory thresholds and/or policies, was used in the completion of Steps 6 and 7.

- Step 8 – Identify the important cause-and-effect relationships between human activities and resources, ecosystems, and human communities. This step was largely accomplished with the IWG via the development of the RFFA matrices. Topics related to Step 8 were discussed in several IWG meetings, and these inputs, along with the RFFA matrices, were used in delineating the cause-and-effect relationships.

- Step 9 – Determine the magnitude and significance of cumulative effects. Again, the IWG participated in this step via discussions on the findings from several research studies as noted above, as well as "best professional practices" for both magnitude determinations and significance assessments. For the ORMSS,

significance relates to major changes (either positive or negative) in the long-term sustainability of a given resource type.

- Step 10 – Modify or add alternatives to avoid, minimize, or mitigate significant cumulative effects. The IWG participated with the CPT in identifying ES needs, including mitigation for the aquatic and some riparian/floodplain ecological resources. The emphasis was on what is needed from a resource perspective, not on what agency has the authority or funding for mitigation. The ES needs approach is the fourth method described herein. For the ORMSS, a primary reason for deferring mitigation until late in the CEA process was the concept that mitigation planning should not begin until the impacts have been determined.

- Step 11 – Monitor the cumulative effects of the selected alternative and adapt management. The key criteria being used to "trigger" Step 11 are the past, present, and future ES categories for the VECs and subcomponents. Through reviews of draft VEC chapters, the IWG has participated with the CPT, along with the OB, in further scoping and decision-making related to this step.

A.3.4 Conclusions and Lessons Learned

A multi-component process for scoping was used in conjunction with this study of the cumulative effects of 19 lock and dams, and numerous other actions, on 12 VECs identified for the 981-mile length of the mainstem of the Ohio River. One unstated thesis herein was that scoping does not refer solely to a single event or meeting; rather, it is a process that can include several mutually supportive and beneficial components. Further, and as demonstrated herein for this CEA study that is preparatory to a navigation SIP/PEIS for the Ohio River mainstem, the features of scoping can be beneficially extended throughout the planning and conduction of a CEA study (i.e., scoping is an on-going and iterative process).

The scoping process design includes specific duties and/or purposes associated with six integrated components; namely, the CPT, two committees (the OB and IWG), 12 scoping meetings, a questionnaire, and the ORMSS website. The CPT, as the representative of the lead agency, provided the leadership in planning and implementing the CEA study. Valuable policy input has been received from the OB and scientific information from the IWG; and the IWG has been actively engaged in providing technical advice and reviews of prepared documents. The scoping meetings, questionnaire results, and website have facilitated information dissemination and generated input on cumulative effects issues and contributory actions. The integration of information from each of the components of the scoping process is illustrated via a step-by-step discussion of how the 11 steps in the CEQ's procedure have been applied in the CEA study.

Based upon the information presented herein, the following conclusions and lessons learned can be articulated:

- As illustrated by this example, scoping should be viewed as an important continuing, iterative process that can facilitate the integration of CEA within a large-scale SIP/PEIS. This "continuing process" is particularly important when dealing with largely unprecedented impact studies at the programmatic level.

- Due to the relative newness of CEA within impact studies, particularly at the programmatic level, it is important that an educational component related to cumulative effects be incorporated in all components of the scoping process.

- An interagency and multiple stakeholder working group, such as the IWG, can provide invaluable input relative to scoping and various levels of participation in a CEA study.

- A multi-component scoping process can provide a more robust input to planning and conducting a CEA study than a process comprised only of one to several scoping meetings.

- The 11-step CEA procedure developed by the CEQ provided a useful framework for conducting a comprehensive study of the cumulative effects of past, present, and reasonably foreseeable future actions on key resources, ecosystems, and human communities along and within the mainstem of the Ohio River; further, it provided a useful framework for designing a unique scoping process for a CEA study.

- The designed scoping process needs to include sufficient flexibility so as to facilitate adjustments over the period of time required for a SIP/PEIS to be prepared.

A.4 RFFA MATRICES

A method involving matrices for connecting RFFAs with anticipated effects on VECs and their components was developed for this study. This method is described herein, beginning with a subsection related to the challenges associated with identifying and analyzing RFFAs. The major subsection relates to the process for developing, completing and using 22 RFFA matrices. The last two subsections, respectively, delineate lessons learned about the completion of the matrices, and about the various uses of the results in the overall CEA study.

A.4.1 Background on RFFAs

The RFFA wording in the cumulative effects (impacts) definition included in Chapter 1 suggests that there should be some level of certainty related to the action, and that it should not be simply speculative or hypothetical. Further, RFFAs may be promulgated by Federal and non-Federal agencies, and by the private sector. In addition, such RFFAs could occur as a part of general population growth and economic development. Finally, another important implication of the above definition is that the RFFAs must impact the same resources, ecosystems, and human communities that are being impacted by the proposed action, in this case, the navigation system investment plan (Council on Environmental Quality, 1997).

Many pragmatic questions have arisen regarding how to incorporate RFFAs into cumulative effects studies. Examples of such questions and relevant responses for this study include:

(1) Should contacts regarding RFFAs be made with governmental agencies beyond the "proponent agency" (i.e., the Corps in this case)? Should private sector developers also be contacted? The answer is "yes" to both questions. The emphasis should be on those RFFAs within the cumulative effects study area as well as those relevant to resources, ecosystems, and human communities affected by the proposed action. The study area for the Ohio River mainstem includes the river itself and the 500-year floodplain and contiguous counties.

(2) How can pertinent RFFAs be identified when agency/developer contact persons indicate they are "not sure that an action will be taken" or they do not identify possible future actions despite their existence? The study team must ask questions related to the timing associated with the planning of a future project (action). Further, information on RFFAs was assembled via 12 public scoping meetings, collaboration with the IWG, individual contacts with multiple public and private entities, and review of information from procured reports and the Internet.

(3) How can the likelihood of occurrence of an RFFA be established? Categories such as high, medium, and low likelihood were used herein, with such likelihoods being assigned for each RFFA based on multiple sources of information as noted in (2).

(4) How can a quantitative approach be used when detailed information about RFFAs is generally lacking? A quantitative approach was not possible for all RFFAs due to the high cost of information procurement at the programmatic level, thus qualitative descriptions and analyses were typically used. However, when quantitative information was readily available, it was used.

(5) How can RFFAs be reasonably identified in large geographical areas typically associated with programmatic impact studies? A variety of information sources such as those noted in (2) above were used, along with historical trends data, various land use planning and economic development reports, contacts with local and regional experts, and analyses of future regulatory programs.

(6) Should future governmental programs, regulations, or standards related to environmental quality and natural resources be considered as RFFAs? Definitely yes. Consideration of these types of RFFAs can be beneficial relative to protecting key resources, ecosystems, and human communities, and incorporating ES features in management efforts.

(7) Are cumulative effects (impacts) simply the sum of the direct and indirect effects (impacts) of a proposed action? Regarding this question, the CEQ regulations contain the following definitions (Council on Environmental Quality, 1978):

Direct effects are caused by the action and occur at the same time and place. Indirect effects are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable. Indirect effects may include growth inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems.

A key point from these definitions is that RFFAs that are not related to the proposed action (the navigation system investment plan) can occur in the same geographical area of the proposed action. Cumulative effects analysis requires the consideration of "total effects" (direct and indirect) from the proposed action along with effects from other past, present, and future RFFAs not related to the proposed action. This "total effects" perspective was used in this study. Therefore, cumulative effects can be the sum of similar impacts from multiple actions, or the product, synergistically, of seemingly unrelated impacts from a variety of actions. In addition, cumulative effects may be countervailing in that a particular type of action would offset the effects of another type of action. Accordingly, cumulative effects arise from actions that may be connected only by their common impacts on similar resources, ecosystems, or human communities.

The identification and analysis of RFFAs presents several challenges in a CEA study. For example, and as noted above, the actual or potential proponents of such future actions may be reluctant to disclose information that could ultimately appear in a PEIS. Early disclosure of such information could lead to controversy about an action that is not completely designed or evaluated. It could also cause speculative changes in land values and thus increase the project costs, or it could jeopardize permit procurement activities that might be in progress. Further, it should be recognized that disclosure reluctance can be due to the fact that final decisions have not yet been made by agency or private sector decision-makers on pursuing a specific action.

A second challenge is that even when RFFAs can be identified, it is unlikely that detailed design and operational information will be available, thus hindering site-specific analysis of cumulative effects, particularly where quantitative emphases would be valuable. The implication is that the effects of each RFFA must be qualitatively identified based on accumulated knowledge of typical "impact footprints" for the types of actions. Furthermore, even if preliminary design information is available on a RFFA, the design details and specific location may change over the time period prior to the actual construction and operation of the project.

A third challenge is related to the multiple influences which may dictate timing, location, and design and mitigation features of a specific future action. For example, future economic influences may be both a key and relatively uncertain influence. Changing environmental regulations can also influence numerous specific design and mitigation features of an action. Such changes can be more stringent or less demanding relative to current regulatory conditions. Finally, decisions on certain actions may be affected by decisions on connected or related actions, thus combinations of RFFAs may need to be considered in the analysis of cumulative effects.

A final challenge is to address the range of "definitions" of RFFAs as found in approximately 40 NEPA-related court case decisions in the United States (Rumrill and Canter, 1997). To illustrate, one to several court cases can be identified for each of the following range of "definitions" of RFFAs:

- Only formal proposals are required to be considered as RFFAs
- Informal proposals beyond speculation are to be considered as RFFAs

- Remote or speculative informal proposals are not required to be considered as RFFAs

- Future actions that are a direct consequence of the current action, and where consideration could alter the nature of the project or its effects, are to be considered as RFFAs

- Geographic connections require actions to be evaluated together

- Geographic connections do not require actions to be evaluated together

- Common natural resources threats or environmental effect connections require actions to be evaluated together

- Planning document related actions supporting defined goals are connected and are to be considered as RFFAs

This range of definitions was considered in the development of the RFFA matrix approach for the CEA study for the mainstem of the Ohio River.

A.4.2 RFFA Matrices – Development, Completion and Usage

This subsection highlights the development and structure of the matrices, the team approach for completion and review of the matrices, and a brief summary of the findings from the completed matrices. The RFFA matrix approach was developed by the CPT.

A.4.2.1 Development Process for the Basic Matrices

A fundamental principle related to planning a CEA study is to focus on the potentially affected resources, ecosystems, and human communities (Rs, Es, and HCs). In a project-level study the focus is typically on the effects of that project on specific Rs, Es, and HCs. When cumulative effects are considered, each R, E, and HC potentially affected by the proposed action must be examined from the perspective of all past, present, and RFFAs that have or might contribute to each effect. Therefore, an early activity in this CEA study was to identify relevant Rs, Es, and HCs. This was accomplished via the continuous scoping process described in the previous section. Twelve Rs, Es, and HCs were identified as VECs, a term used in Canadian cumulative effects studies. Three of the 12 original VECs included subcomponents.

The original perception of the CPT was that one "overall matrix" could be developed for the ORMSS cumulative effects study. The overall matrix would have included all the identified RFFAs and the VECs and their subcomponents together. However, due to expediency relative to matrix completion, it was recognized that individual matrices would be needed for the 12 VECs. For the three VECs with multiple components (Aquatic Ecological Resources, Riparian/Floodplain Ecological Resources, and Threatened/Endangered /Protected Species), additional matrix columns were envisioned. However, it was soon recognized that matrices focused on single subcomponents within VECs, or single VECs themselves, would be more useable. As a result, 22 matrices were used; the listing is in the left column of **Table A-5**.

TABLE A- 5
Summary of Process Features Related to Completion of the RFFA Matrices

VEC	Preparation of Matrix	Review and Summarization of Matrix
AER – Water Quality/Sediment Quality	CPTC	CPT
AER – Fish	ERTC	CPT
AER – Mussels	IWGC (Note 1)	CPT
Air Quality	CPTC	CPT
RFER – Terrestrial Habitat	IWGC	CPT
RFER – Islands	IWGC	CPT
RFER – Wetlands	IWGC	CPT
RFER – Soils and Geology	IWGC	CPT
RFER – Floodplain Hydrology	IWGC	CPT
T/E/P Species – Fish	IWGC	CPT
T/E/P Species – Mussels	IWGC	CPT
T/E/P Species – Mammals	IWGC	CPT
T/E/P Species – Birds	IWGC	CPT
T/E/P Species - Plants	IWGC	CPT
Aesthetic Resources	CPTC	CPT
Noise	CPTC	CPT
Human Health and Safety	CPTC	CPT
Land Use	CPTC	CPT
Transportation and Traffic	CPTC	CPT
Socioeconomic Resources	CPTC	CPT
Cultural Resources	CPTC	CPT
Recreation	CPTC	CPT

Notes: CPTC = central planning team committee (3-4 members)
CPT = central planning team
IWGC = interagency working group committee (3-4 members)
Note 1 = it was assumed that T/E/P Species-Mussels RFFA Matrix is applicable to AER-Mussels
AER = aquatic ecological resources
RFER = riparian/floodplain ecological resources
T/E/P Species = threatened/endangered/protected species

A.4.2.2 Structure of the RFFA Cumulative Effects Matrices

The definition for RFFAs was included in the Step 4 description in the CEQ Procedure section of this chapter. **Table A-6** displays the RFFA cumulative effects matrix which was used for the water and sediment quality VEC. The 87 RFFAs were divided into six categories: (1) navigation investment actions; (2) other Corps actions; (3) "but for" actions; (4) actions by others (could occur regardless of the Ohio River navigation system); (5) natural disasters; and (6) regulatory environment. "But for" actions refer to those actions by others which would not occur except for the existence and maintenance of the Ohio River navigation system. Natural disasters are included since floods, droughts, severe storms, and/or earthquakes can have major influences on many of the VECs and subcomponents. Definitions for each of the listed types of RFFAs are available in Exhibit B. Under the ORMSS, only "navigation investments actions" are being evaluated programmatically for federal action.

The second column in **Table A-6** relates to sources of information that were the basis for the listed RFFA. Sources included plans, permits, census data, other EAs (environmental assessments) and EISs, surveys, map and/or navigation chart (Navchart) analyses, trends analysis data (TAD), and professional opinion. A summary of the utilized sources is available in Exhibit B.

The next three columns in **Table A-6** highlight relative characteristics of the listed RFFAs. The following definitions relate to the "codes" which were used for each of the characteristics (the codes are defined at the bottom of **Table A-6**).

(1) Time Period-short, medium and long-term. Short-term is the initial 10-year period from the point of completion of the CEA study (2005) and is based upon the probability of occurrence, availability of information, status of funding, and other factors. The medium time frame is from 10 to 25 years beyond 2005. The long-term period is 25 to 55 years. The date of 55 years is based on the economic analysis period for the navigation investment plan (to 2060).

(2) Occurrence Probability- high, medium, and low. High denotes substantial information exists and funding is already in place (already "on the books"). Medium denotes some information is available, and some funding possibilities exist. Low denotes minimal information and no identified funding or proponent.

(3) Location on River- Three reaches of the River were routinely used (upper, middle, or lower); the upper reach was from Pittsburgh to approximately Huntington, West Virginia; the middle reach was from Huntington, to Louisville, Kentucky; and the lower reach was from Louisville to Cairo.

The final three columns relate to the effects on the VEC or sub-component thereof, and the overall importance of the RFFAs regarding cumulative effects. The key display information in the two VEC-related columns was associated with whether the RFFA exhibits negative or positive effects. Descriptive rationale for this determination was entered in "smart cells" as follows. The RFFA matrices were provided to each committee as Microsoft® Excel spreadsheets. The "insert comment" function was used to access a detailed definition of each RFFA. Committee members were able to read each definition by moving their cursor over the RFFA cell. The committee was also encouraged to insert

comments to expand upon coded entries. This proved most useful when the team was describing the effects on the VEC or subcomponent, and rating the relative importance of the RFFA's impact. In so doing, the issues or values most important in the formulation of their entries were identified. Although use of the comments function was optional, committees often provided comments for all of their high and medium importance entries. Detailed information on the "smart cell" contents for all matrices is available elsewhere (U.S. Army Corps of Engineers, 2003).

TABLE A-6
RFFA Cumulative Effects Matrix for Water and Sediment Quality

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Navigation Investment Actions							
Lock Extensions/New Locks/Replacement or Rehabilitation	Corps planning (districts); ORNIM study outputs						
L&D operation and maintenance	Corps O&M records, J.T. Myers & Greenup Locks Improvements EIS						
Non-structural navigation improvements	Examples from: Upper Mississippi - Illinois Waterway report, national park studies.						
Dam replacement and rehabilitation	(Category added by review team)						
Other Corps Actions							
Channel dredging/dredged material disposal	Corps (districts), J.T. Myers & Greenup Locks Improvements EIS						
Navigation aids - Construction and O&M	Corps historic records, trends related to GPS, 1980 Corps O&M EIS						
Flood damage reduction projects							
levees/floodwalls	EAs and EISs from individual communities, Corps O&M records, ERP projects list						
dry dams, other projects off mainstem	EISs in Corps planning offices (districts), projects planned on tributaries						
channel modifications	Point Pleasant project, projects planned on tributaries						
nonstructural measures (e.g. relocation)	FEMA, flood relocation reports, Corps planning, Mill Creek project						
Emergency streambank stabilization (Sec. 14)	Corps planning & operations (districts)						
Modification of Corps structures for environmental improvements (Sec. 1135)	Corps planning & operations (districts)						
Environmental restoration of aquatic ecosystems (Sec. 206)	Corps planning & environmental offices (districts), EA for ERP						
Recreation facilities - Construction and O&M	Corps recreation planning, and operations (districts), navigation charts						
ERP Projects - 5 categories	EAs for ERP divided by habitat type						

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Port development (Sec. 107) and maintenance dredging	Corps planning, operations & historic records, state port authorities, state plans						
Pool maintenance	(Category added by review team)						
"But for" Actions							
Commercial Navigation							
barge queuing	Corps traffic forecasts/planning/ operations Queuing data from EMD, J.T. Myers & Greenup Locks Improvements EIS						
fleeting areas/barge storage	Navigation charts, Sec.404 permits, US Coast Guard						
terminals	Navigation charts, Sec.401 & 404 permits, Mangi questionnaire						
multi-modal sites	Navigation charts, riverfront development plans, Mangi questionnaire, state transportation improvement plans						
increased traffic	Corps traffic forecasts by Huntington economics group						
dispersed barge traffic	US Coast Guard watercraft safety records, existing and proposed recreational users' surveys, barge operators' associations						
barge/tow tech/"green" design	equipment manufacturers, barge operators' associations, examples from other countries						
accidents/spills	ORSANCO database, USEPA, emergency response groups						
Coast Guard Nav. Aids - Construction, O&M	US Coast Guard, navigation charts						
Instream sand and gravel mining	State mineral extraction agencies, 1981 Corps EIS, Corps economics group (Huntington)						
Floodplain sand and gravel mining	State mineral extraction agencies, navigation charts, aerial photos						
Limestone aggregates mining	State mineral extraction agencies, navigation charts, aerial photos, National Mining Association						
Coal utilities	DINAMO, Corps economics team (Huntington), state utility regulators, NPDES permit holders						
Other coal industries	DINAMO, Corps economics team (Huntington), state utility regulators, NPDES permit holders						
Hydropower on dams	FERC, ORSANCO, Corps (districts), 1988 EIS on hydroelectric power on the Upper Ohio River, state tourism departments						
Water intakes	ORSANCO, navigation charts, individual communities						

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Industrial users, excluding coal-related	ORSANCO , NPDES permits						
Recreation facilities - Construction and O&M	State tourism offices, DNRs, SCORPs, Land & Water Conservation Fund						
Traffic effects due to new locks	Added by Aquatic VEC subgroup						
Actions by Others							
Public lands acquisition and management	Nature Conservancy, Audubon, L&WCF, Forest Plans, DNR strategic plans						
Floodplain development							
residential	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,						
commercial	(same as above)						
industrial	(same as above)						
Private recreational sites: campgrounds, docks, and seasonal trailer parks	(Category added by review team)						
Crossings							
bridges	State transportation plans, KY bridges and Corridor D (WV) web sites, EISs,						
utility	navigation charts, US Coast Guard, FERC, Sec.404 permits						
industrial	navigation charts, US Coast Guard, FERC, Sec.404 permits						
Riverbed crossings	navigation charts, Corps planning (district)						
Marina development & operation	navigation charts, historic trends, LANDSAT, Sec.404 & NPDES permits						
Water -based recreation							
boating	State boat registration agencies, recreation surveys						
fishing	State resource agencies, recreation and creel surveys						
PWCs	State boat registration agencies, recreation surveys						
hunting	State resource agencies, recreation surveys						
wildlife watching	State resource agencies, NAWMP, recreation surveys, environmental groups						
sight-seeing	State tourism offices,						

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Silviculture	NRCS, state resource agencies, woodland management associations						
Agriculture	NRCS, state agricultural agencies, aerial photos						
WWTP discharges							
municipal	ORSANCO, navigation charts, NPDES permits, state regulatory agencies						
industrial	ORSANCO, navigation charts, NPDES permits, state regulatory agencies						
onsite systems	County & state health dept., sewer system maps, census data						
Stormwater discharges	Stormwater utilities, Phase 1 & 2 communities, exempt communities (CSOs)						
Brownfields redevelopment	Riverfront dev. plans, port authorities, federal and state brownfields redevelopment funding authorities						
Trail/bikeway development	Regional planning organizations, Rivers & Trails Assistance program, state plans						
Casinos	State gaming commissions						
Hazardous waste sites	HAZMET inventory						
Natural Climatic Events							
floods	Historical data from Corps, FEMA, state climatology agencies						
droughts	Historical data from NOAA						
severe storms	Historical data from NOAA						
earthquakes	Data from USGS, state geological surveys, earthquake hazard maps						
Regulatory Environment							
Phase I & 2 NPDES program	USEPA Regulatory Agenda Updates (RAU), state agencies, CWA amendments						
TMDLs	USEPA RAU, state agencies, ORSANCO, CWA amendments						
Site remediation	USEPA RAU, amendments to RCRA, CERCLA & SARA, state laws/updates						
More stringent quality standards for environmental media	USEPA RAU, amendments to CAA, CWA, SWDA & RCRA, state agencies administering federal laws						
Pollutant source control	USEPA RAU, amendments to CAA, CWA, SWDA & RCRA, state agencies administering federal laws						
Wetland Mitigation Banking	Updates to federal guidance by Corps, USEPA, NRCS, USFWS and NOAA;						
Carbon sequestration	US Dept. of Energy						
Farmland preservation	Policy updates from NRCS, amendments to federal Farm Bills, state agencies						

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Effluent trading	Policy, regulatory updates from USEPA, amendments to CWA; ORSANCO, state water and/or pollution control agencies						
Agricultural discharges	USEPA RAU, CWA amendments, state agencies, US Dept. of Agriculture						
Pollution Prevention	USEPA RAU, amendments to PPA, federal/state voluntary program initiatives.						
Emissions trading	Policy, regulatory updates from USEPA, amendments to CAA, state, regional or local air quality management programs						
COE permitting programs	Corps (districts, division, and HQ), amendments to CWA, WRDA, other laws						
Small navigation projects	Corps (headquarters), amendments to RHA and WRDA						
Boating safety regulations	Policy, regulatory updates from USDOT and US Coast Guard, pertinent state agencies, national boating organizations						
ORSANCO monitoring program	ORSANCO, USEPA regulatory updates, amendments to CWA & SWDA, USFWS policies & regulatory updates (ESA)						
Spill response	ORSANCO, policy and/or regulatory updates to Section 301 of CWA, amendments to CWA and SDWA						
Information and FOIA	Policy and/or regulatory updates to FOIA, amendments to FOIA						
Environmental Awareness Education	USEPA policies and programs, educational components of CWA, SDWA, CAA, RCRA, ESA, state programs						
ESA (Endangered Species Act)	USFWS policy, regulatory changes, recovery plans & candidate species list, ESA amendments, OR Valley Ecosystem Team, biological assessment for ORMSS						
Environmental sustainability practices	President's Council on Sustainable Development, environmental NGOs						

[1] Reasonably Foreseeable Future Actions
[2] Plans, regulations, sampling data, maps, trend analyses, etc.
[3] Time period in which the RFFA may occur
1 = within 10 years, 2 = in 10 - 25 years, 3 = in 25 - 55 years, A = applicable for all time periods
[4] Occurrence probability or likelihood RFFA will happen
H = high, M = medium, L = low
[5] Location or setting on river where RFFA is expected to occur
U = upper (Pittsburgh - Huntington), M = middle (below Huntington - Louisville)

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
L = lower ((below Louisville - mouth), A = along entire length of river SL = specific location, e.g. locks and dams, U = urban setting, R = rural setting [6]Importance of RFFA H = high, M = medium, L = low							

Actual completion of an individual "cell" in a matrix was based upon a series of considerations. To illustrate, **Table A-7** lists questions and example responses related to the effects of barge queuing (an RFFA) on water quality (a subcomponent of the aquatic ecological resources VEC). The first three questions are related to the characteristics of the RFFA, while the last six questions are associated with the characteristics of the anticipated effects. It is recognized that the development of thorough, written answers to each of the nine questions for each RFFA for each matrix would be overwhelming. To illustrate, with 87 identified RFFAs, 22 matrices (VECs or subcomponents), and 9 questions each, a total of 17,226 questions would need answers! Accordingly, the nine questions were considered as a potential generic checklist of things to think about for water quality, with specific responses grouped in a shorthand manner to provide documentation.

The final column in **Table A-6** is entitled "Importance". In this case, the committee assigned an "importance rating" to all RFFAs identified as having effects. The rating code was H (high importance), M (medium importance), or L (low importance). Again, notes were added to the respective "smart cells" in the Importance column to denote the rationale used. Some things that were considered included: (1) the relative contribution of the RFFA to the cumulative effects; (2) the spatial and temporal extent of the anticipated effects; (3) the level of knowledge regarding the affected VEC or subcomponent, and the effects themselves, and (4) the possibilities for cost-effectively mitigating the negative effects.

TABLE A-7
Questions for Consideration in Completing the Cells in a Matrix
(An example related to barge queuing, an RFFA, and water quality, a subcomponent of the aquatic ecological resources VEC)

- **Questions Related to the Characteristics of the RFFA**

  (1) Time Period – How frequently will the RFFA (barge queuing) take place? Repeatedly occurring under current conditions with frequency directly related to traffic congestion and lock closures for repairs.

  (2) Occurrence Probability – What is the probability of occurrence of the RFFA (barge queuing)? High, under current conditions.

  (3) Location on River – What is the anticipated location of the RFFA (barge queuing) along the river? Wherever barge congestion occurs at locks.

- **Questions Related to the Effects of the RFFA**

  (1) What are the anticipated effects of the RFFA (barge queuing) on the VEC or subcomponent of the VEC (water quality)? Increased localized velocities create

turbulence causing bottom scouring, resuspension of sediments, release of contaminants into the water column, volatilization of some contaminants, reduction in thermal stratification; also, a temporary increase in oxygen due to aeration by barges can occur, followed by a decrease in oxygen related to increased turbidity.

(2) What is the anticipated "area of occurrence" of the effects? Vicinity of locks.

(3) What is the duration of the RFFA (barge queuing) and the related effects? Relatively short (hours or days).

(4) What is the recoverability or reversibility of the effects on the VEC or subcomponent of the VEC (water quality)? Relatively quick recovery of conditions in the water column will occur, but longer-term impacts are related to release of contaminated sediments and bottom deposition.

(5) What regulatory standards or policies apply to the effects, and will they be violated? Effects are not likely to cause exceedances of instream water quality standards for dissolved oxygen or turbidity.

(6) What are the anticipated effects of the RFFA on other VECs or components thereof? Includes reduced algae productivity resulting from decreased light penetration, redeposition of suspended sediments on habitat of mussels and other benthic organisms and bottom-feeding fishes, and shoreline erosion with attendant increases in bedload of sediments and loss of trees and other vegetation affecting nutrient levels and further exacerbating shoreline instability.

A.4.2.3 Team Approach for Completion and Review of Matrices

Completion of the 22 matrices listed in Table 5 was a joint endeavor between the study's IWG and CPT. Committees comprised of IWG members and, in some instances, CPT members, prepared 11 matrices; the CPT prepared the remaining 11 matrices. Following the completion of the draft versions of the matrices, they were each reviewed and summarized by the CPT. Details on the membership of each completion and review committee are available elsewhere (U.S. Army Corps of Engineers, 2003).

A.4.2.4 Summary of Completed Matrices

One common feature of all 22 matrices are the columns entitled time period, occurrence probability, and location on River. These columns relate to the features of the RFFAs; thus they have the same codes on all 22 matrices. **Table A-8**, which is a portion of the completed matrix for water and sediment quality, displays the common characteristics of several RFFAs. The following comments summarize these characteristics for all 87 RFFAs:

(1) Eighty-five RFFAs are depicted as occurring over all three time periods. Two RFFAs (carbon sequestration and environmental sustainability practices) are anticipated in the second (10-25 years) and third (25-55 years) periods.

(2) Regarding occurrence probability, 75 RFFAs are listed as high, 9 as medium, and 3 as low.

(3) Fifty-five RFFAs are designated as occurring at specific locations along the River, while 32 are expected to take place along the entire River.

One reason for the high numbers occurring over all three time periods is that the vast majority of RFFAs represent continuations, or possible expansions, of past and present actions. For example, **Table A-9** displays time periods for the actions ranging from before 1950 to beyond 2005. This logic was also basic to the high occurrence probabilities, and the patterns of distribution along the River.

Table A-10 contains tabulations of the numbers of RFFAs causing negative and positive effects on each specified VEC or subcomponent. Detailed information on the effects ratings, importance ratings, and their associated comments in "smart cells" are in the individual matrices; with this information being available elsewhere (U.S. Army Corps of Engineers, 2003).

Table A-8
RFFA Cumulative Effects Matrix for Water and Sediment Quality with Examples of Inserted Comments

RFFA[1]		Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Navigation Investment Actions							
Lock Extensions/New Locks/Replacement or Rehabilitation*		A	H	A	-	-	L
*Description of Category: lock extensions - involves expanding lock chambers from 600' to 1200' at seven projects from R.C. Byrd to Smithland L/D and encompasses all related construction activities, including establishing parking and maintenance areas for equipment and materials, clearing and disposal of vegetation, establishing a disposal area for excess soil and rock, and some earthwork to connect portions of the new lock chamber with the riverbank Lock replacements - involves constructing one 1200' main chamber to replace the 360' auxiliary lock chamber at Emsworth, Dashields and Montgomery L/Ds. The 600' chamber currently in place at each of these projects would remain. Includes related construction activities similar to those associated with lock extension		*Water Quality Comment: Turbidity increase due to construction activities; some flow changes may also occur during construction; localized effects. *Sediment Comment: Negative temporary impacts to sediments related to construction impacts. Also, long term impacts of 19 lock & dam projects on sediment transport throughout the river system. *Importance Comment: Low importance due to minimal occurrences over the study period; mitigation measures to be used during construction.					
L&D operation and maintenance		A	H	A	-	-	M
Lock maintenance, repair and rehabilitation - involves activities that require temporary closure of a lock chamber, including periodic upkeep, major and minor repairs of lock chambers and more long-term restoration projects	*Water Quality Comment: Water surges from operation may cause temporary localized impacts to turbidity and sediments.	*Sediment Comment: Negative temporary impacts to sediments related to construction impacts and long term impacts of 19 lock & dam projects on sediment transport throughout the river system.			Importance Comment: Medium importance due to high frequency of occurrence at multiple locations over the study period.		
Non-structural navigation improvements		A	H	A	+	+	L
Dam replacement and rehabilitation		A	H	A	-	-	L
Other Corps Actions							
Channel dredging/dredged material disposal		A	H	A	-	-	H

RFFA[1]			Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Channel dredging/dredged material disposal - refers to removal and disposal of sand and gravel deposits from the navigation channel of the Ohio River to maintain a nine-foot depth.	Water Quality Comment: Dredging can cause negative effects due to increased turbidity and possible sediment contaminant releases.	Sediment Comment: Sediment movement and contaminant releases can occur.	Importance Comment: High importance due to magnitude of effects at several possible locations.					
Flood damage reduction projects								
levees/floodwalls			A	L	A	-	?	L
dry dams, other projects off mainstem			A	L	A	-	?	M
Off mainstem projects - include structures located along tributaries that retain or detain surface runoff to alleviate downstream flooding	Water Quality Comment: Dam operations can have both beneficial and detrimental effects on water quality.	Importance Comment: Medium importance since there are numerous upstream dams on the tributaries.						
ERP Projects - 5 categories			A	M?	A	+	+	M
ERP projects (5 habitat types) - projects encompassed by the Ohio River Ecosystem Restoration Program (ERP), aimed at the restoration of significant ecosystem function, structure and dynamic processes that have been degraded. ERP partners would include federal and state resource agencies and regional environmental resource groups. The five broad habitat types involved are: 1) bottomland hardwood forests, 2) aquatic habitat, 3) islands, 4) shoreline/riparian habitat and 5) wetlands.	Water Quality Comment: Beneficial effects since aquatic and riparian projects would be expected to have improvements to water quality as an objective.	Sediment Comment: Beneficial effects: projects would be expected to have sediment quality improvement as an objective.	Importance Comment: Medium importance due to the potential for a large number of projects over the study period. Note also, potential cumulative benefits of related restoration programs.					
Port development (Sec. 107) and maintenance dredging			A	H	A	-	-	M
Port development and maintenance dredging - authorized by Section 107 of the Rivers and Harbors Act of 1960, as amended; permits the Corps to construct small river and harbor improvement projects not specifically authorized by Congress when they will result in substantial benefits to navigation.	Water Quality Comment: operations may cause temporary localized impacts to turbidity and sediments, also would have turbidity increases due to periodic maintenance dredging, localized effects.	Sediment Comment: sediment disturbances during construction and maintenance dredging; localized effects.	Importance Comment: medium impacts due to scale of port developments and ongoing activity.					
"But for" Actions								
Commercial Navigation								
fleeting areas/barge storage			A	H	A	-	-	M
Fleeting areas / barge storage - areas where harbor towboats assemble, dissemble and reassemble barge tows into different configurations, according to their delivery destinations; includes temporary instream storage of surplus barges	Water Quality Comment: operations may cause temporary localized impacts to turbidity and sediments, may also get oil products from tows, could get rust from barge storage.	Sediment Comment: Resuspension of localized sediments.	Importance Comment: Medium importance due to routine occurrence over the study period and several locations along the mainstem.					

RFFA[1]				Time Period[3]	Occurrence Probability[4]	Location on River[5]	Water Quality	Sediment Quality	Importance
Terminals and/or multi-modal sites				A	H	A	-	-	M
Terminals - facilities at either end of a shipping line where materials are unloaded, loaded or temporarily stored; also may serve as intermediate ports where fleeting activity occurs Multi-modal sites - port facilities involving more than one mode of transportation (e.g. rail connection at terminal).	Water Quality Comment: operations may cause temporary localized impacts to turbidity and sediments, plus localized effects from barge operations.	Sediment Comment: Local sediment disruption during construction and barge operations.	Importance Comment: Medium importance due to routine occurrence over the study period and several locations along the mainstem.						
Increased traffic				A	H	A	-	-	M
Increased traffic - refers to additional barge traffic on the Ohio River with or without future improvement to the lock and dam system.	Water Quality Comment: Turbidity increases due to barge-tow travel within the mainstem.	Sediment Comment: Sediment Resuspension	Importance Comment: Medium importance due to cumulative effect of multiple sources plus possible synergistic effect of increased concentration and reduced recovery time between impacts.						
Accidents/spills				A	H	A	-	-	M
Accidents/spills - refers to barge traffic accidents and spillage of shipping materials while in transit or storage	Water Quality Comment: Degradation of several water quality parameters, depending on sizes and types of spills/accidents.	Sediment Comment: Possible sediment contamination from released products and chemicals.	Importance Comment: Low importance due to minimal occurrences and existing countermeasure plans for control and clean-up.(LC) Suggest medium importance due to continued occurrence of major spills that kill biota &/or threaten water supplies – e.g. Winter 2000/Spring 2001 sludge spill in Big Sandy that threatened water supplies through Cincinnati. [EH]						
Instream sand and gravel mining				A	H	A	-	-	H
Instream sand and gravel mining - commercial extraction of sand and gravel from the Ohio River itself	Water Quality Comment: Turbidity increases and releases of sediment contaminants in mining areas; localized effects of possible large magnitudes.	Sediment Comment: Disruptions in sediment deposits.	Importance Comment: High importance due to magnitude of effects at several possible locations.						
Coal utilities				A	H	A	-	-	H
Coal utilities - refers primarily to power stations located along the Ohio River which burn coal to generate electricity for their customers	Water Quality Comment: Thermal pollution and possible chemical pollution from corrosion inhibitors, and suspended discharges from coal piles.	Sediment Comment: Sediment discharges could have some chemical pollutants associated therewith.	Importance Comment: High importance due to number of utility plants and quantities of point and nonpoint discharges; are subject to point and nonpoint source standards.						

TABLE A-9
Timeframe of Reasonably Foreseeable Future Actions (RFFAs)

RFFA[1]	Sources[2]	Applicable Time Period[3]
Navigation Investment Actions		
Lock Extensions/New Locks/Replacement or Rehabilitation	Corps planning (districts); ORNIM study outputs	All
L&D operation and maintenance	Corps O&M records, J.T. Myers & Greenup Locks Improvements EIS	All
Non-structural navigation improvements	Examples from: Upper Mississippi -Illinois Waterway report, national parks congestion management strategies, other countries	P3, Pr, F
Dam replacement and rehabilitation		P2, P3, Pr, F
Other Corps Actions		
Channel dredging/dredged material disposal	Corps (districts), J.T. Myers & Greenup Locks Improvements EIS	All
Navigation aids - Construction and O&M	Corps historic records, trends related to GPS, 1980 Corps O&M EIS	All
Flood damage reduction projects		
levees/floodwalls	EAs and EISs from individual communities, Corps O&M records, ERP projects list	All
dry dams, other projects off mainstem	EISs in Corps planning offices (districts), projects planned on tributaries	All
channel modifications	Point Pleasant project, projects planned on tributaries	All
nonstructural measures (e.g. relocation)	FEMA, flood relocation reports, Corps planning, Mill Creek project	All
Emergency streambank stabilization (Sec. 14)	Corps planning & operations (districts)	P3, Pr, F
Modification of Corps structures for environmental improvements (Sec. 1135)	Corps planning & operations (districts)	P3, Pr, F
Environmental restoration of aquatic ecosystems (Sec. 206)	Corps planning & environmental offices (districts), EA for ERP	Pr, F
Recreation facilities - Construction and O&M	Corps recreation planning, and operations (districts), navigation charts	All
ERP Projects - 5 categories	EAs for ERP divided by habitat type	F
Port development (Sec. 107) and maintenance dredging	Corps planning , operations & historic records, state port authorities, navigation charts, state transportation plans	P2, P3, Pr, F
Pool maintenance		All
"But for" Actions		
Commercial Navigation		
barge queuing	Corps traffic forecasts, planning & operations, queuing data from EMD, J.T. Myers & Greenup Locks Improvements EIS	All
fleeting areas/barge storage	Navigation charts, Sec.404 permits, US Coast Guard	All
terminals	Navigation charts, Sec.401 & 404 permits, Mangi questionnaire	All
multi-modal sites	Navigation charts, riverfront development plans, state transportation improvement plans	All
increased traffic	Corps traffic forecasts by Huntington economics group	All

RFFA[1]	Sources[2]	Applicable Time Period[3]
dispersed barge traffic	US Coast Guard watercraft safety records, existing and proposed recreational users' surveys, barge operators' associations	P2, P3, Pr, F
barge/tow tech/"green" design	equipment manufacturers, barge operators' associations, examples from other countries	Pr, F
accidents/spills	ORSANCO database, USEPA, emergency response groups	All
Coast Guard Nav. Aids - Construction, O&M	US Coast Guard, navigation charts	All
Instream sand and gravel mining	State mineral extraction agencies, navigation charts (?), 1981 Corps EIS, Corps economics group (Huntington)	All
Floodplain sand and gravel mining	State mineral extraction agencies, navigation charts, aerial photos	All
Limestone aggregates mining	State mineral extraction agencies, navigation charts, aerial photos, National Mining Association	All
Coal utilities	DINAMO, Corps economics team (Huntington), state utility regulators, NPDES permit holders	All
Other coal industries	DINAMO, Corps economics team (Huntington), state utility regulators, NPDES permit holders	All
Hydropower on dams	FERC, ORSANCO, Corps (districts), 1988 EIS on hydroelectric power on the Upper Ohio River, state tourism departments	All
Water intakes	ORSANCO, navigation charts, individual communities	All
Industrial users, excluding coal-related	ORSANCO , NPDES permits	All
Recreation facilities - Construction and O&M	State tourism offices, DNRs, SCORPs, Land & Water Conservation Fund	All
Traffic effects due to new locks	Added by Aquatic VEC subgroup	F
Actions by Others		
Public lands acquisition and management	Nature Conservancy, Audubon Society, Land & Water Conservation Fund, Pt. Pleasant Riverfront Park Feasibilty Study, Forest Management Plans, state forest plans, DNR strategic plans	P2, P3, Pr, F
Floodplain development		
residential	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,	All
commercial	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,	All
industrial	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,	All
Private recreational sites, including campgrounds, docks, and seasonal trailer parks	Added by Riparian/Floodplain subgroup	All
Crossings		

RFFA[1]	Sources[2]	Applicable Time Period[3]
bridges	State long-term transportation plans, KY bridges and Corridor D (WV) web sites, navigation charts, EISs, River Fields (Louisville) web site	All
utility	navigation charts, US Coast Guard, FERC, Sec.404 permits	All
industrial	navigation charts, US Coast Guard, FERC, Sec.404 permits	All
Riverbed crossings	navigation charts, Corps planning (district)	All
Marina development & operation	navigation charts, historic trends, LANDSAT images, Sec.404 & NPDES permits	All
Water -based recreation		
boating	State boat registration agencies, recreation surveys	All
fishing	State resource agencies, recreation and creel surveys	All
PWCs	State boat registration agencies, recreation surveys	Pr, F
hunting	State resource agencies, recreation surveys	All
wildlife watching	State resource agencies, NAWMP, recreation surveys, environmental groups	All
sight-seeing	State tourism offices, recreation surveys	All
Silviculture	NRCS, state resource agencies, woodland management associations	All
Agriculture	NRCS, state agricultural agencies, aerial photos	All
WWTP discharges		
municipal	ORSANCO, navigation charts, NPDES permits, state regulatory agencies	All
industrial	ORSANCO, navigation charts, NPDES permits, state regulatory agencies	All
onsite systems	County & state health dept., sewer system maps, census data	P2, P3, Pr, F
Stormwater discharges	Stormwater mgmt. utilities, Phase 1 & 2 communities, exempt communities with CSOs and SSOs	All
Brownfields redevelopment	Riverfront dev. plans, port authorities, federal and state brownfields redevelopment funding authorities	Pr, F
Trail/bikeway development	Regional planning organizations, state tourism offices, Rivers, Trails & Con. Assistance program, state transportation plans	P3, Pr, F
Casinos	State gaming commissions	P3, Pr, F
Hazardous waste sites	HAZMET inventory	P3, Pr, F
Natural Climatic Events		
Floods	Historical data from Corps, FEMA, state climatology agencies	All
Droughts	Historical data from NOAA	All
Severe storms	Historical data from NOAA	All
Earthquakes	Historical data from USGS, state geological surveys, earthquake hazard maps	All
Regulatory Environment		
Phase I & 2 NPDES program	USEPA Regulatory Agenda Updates, state agencies administering program, CWA amendments	P3, Pr, F

RFFA[1]	Sources[2]	Applicable Time Period[3]
TMDLs	USEPA Regulatory Agenda Updates, state agencies, ORSANCO, CWA amendments	Pr, F
Site remediation	USEPA Regulatory Agenda Updates, amendments to RCRA, CERCLA & SARA, new or amended state laws	P3, Pr, F
More stringent quality standards for environmental media	USEPA Regulatory Agenda Updates, amendments to CAA, CWA, SWDA & RCRA, state agencies administering federal and state environmental media laws	P3, Pr, F
Pollutant source control	USEPA Regulatory Agenda Updates, amendments to CAA, CWA, SWDA & RCRA, state agencies administering federal and state environmental media laws	P2, P3, Pr, F
Wetland Mitigation Banking	Updates to federal guidance by Corps, USEPA, NRCS, USFWS and NOAA; Institute for Water Resources)	P3, Pr, F
Carbon sequestration	US Dept. of Energy	Pr, F
Farmland preservation	Policy updates from NRCS, amendments to federal Farm Bills, state agriculture or natural resource agencies	P3, Pr, F
Effluent trading	Policy and/or regulatory updates from USEPA, amendments to CWA; ORSANCO, state water and/or pollution control agencies	P3, Pr, F
Agricultural discharges	USEPA Regulatory Agenda Updates, CWA amendments, state regulatory agencies, US Dept. of Agriculture	All
Pollution Prevention	USEPA Regulatory Agenda Updates, amendments to PPA, federal and/or state initiatives for voluntary programs	P3, Pr, F
Emissions trading	Policy and/or regulatory updates from USEPA, amendments to CAA, state, regional or local air quality management programs	P3, Pr, F
COE permitting programs	Corps (3 districts, division, and headquarters), amendments to CWA, WRDA and other pertinent laws	All
Small navigation projects	Corps (headquarters), amendments to RHA and WRDA	P2, P3, Pr, F
Boating safety regulations	Policy and/or regulatory updates from the USDOT and US Coast Guard, pertinent state agencies, national boating organizations	P2, P3, Pr, F
ORSANCO monitoring program	ORSANCO, regulatory updates from USEPA, amendments to CWA and SWDA, policies and/or regulatory updates from USFWS (Endangered Species Act)	P2, P3, Pr, F
Spill response	ORSANCO, policy and/or regulatory updates to Section 301 of CWA, amendments to CWA and SDWA	P3, Pr, F
Information and FOIA	Policy and/or regulatory updates to FOIA, amendments to FOIA	P3, Pr, F
Environmental Awareness Education	USEPA policies and programs, educational components of CWA, SDWA, CAA, RCRA, ESA and natural resources laws (current or based on amendments), state programs	P3, Pr, F

RFFA[1]	Sources[2]	Applicable Time Period[3]
ESA (Endangered Species Act)	Policy and/or regulatory changes of USFWS, amendments to ESA, USFWS candidate species list, recovery plans, OR Valley Ecosystem Team, biological assessment for ORMSS	P2, P3, Pr, F
Environmental sustainability practices	President's Council on Sustainable Development, environmental NGOs	Pr, F

[1] Reasonably Foreseeable Future Actions

[2] Plans, regulations, sampling data, maps, trend analyses, etc.

[3] Time period in which the RFFA may occur:

P1 Before1950 P3 19751995 F Beyond 2005
P2 1950-1975 Pr 1995-2005 All Includes all time periods

Table A-10
Tabulations of RFFAs causing effects on various VECs
(or subcomponents of VECs)

VEC	Number of RFFAs		
	Negative Effects	Positive Effects	No Change
AER – Water Quality/Sediment Quality	43 (4H, 8M, 32L)	21 (2H, 7M, 13L)	22
AER – Fish (see Note 1)	54 (16H, 20M, 18L)	27 (13H, 2M, 12L)	9 (4U)
AER – Mussels (see Note 2)	51 (35H, 9M, 7L)	28 (21H, 5M, 2L)	13
Air Quality	49 (3H, 14M, 32L)	10 (2H, 2M, 6L)	28
RFER – Terrestrial Habitat	50 (37H, 13L)	18 (18H)	20
RFER – Islands	35 (26H, 9L)	17 (17H)	36
RFER – Wetlands	48 (37H, 11L)	21 (21H)	19
RFER – Soils and Geology	38 (30H, 8L)	13 (13H)	37
RFER – Floodplain Hydrology	29 (26H, 3L)	15 (15H)	44
T/E/P Species – Fish	NA	NA	NA
T/E/P Species – Mussels (see Note 2)	51 (35H, 9M, 7L)	28 (21H, 5M, 2L)	13
T/E/P Species – Mammals	33 (18H, 8M, 7L)	3 (2H, 1L)	52
T/E/P Species – Birds (see Note 3)	42 (18H, 24M)	27 (23H, 3M, 1L)	20
T/E/P Species – Plants	30 (14H, 11M, 5L)	16 (1M, 15L)	41
Aesthetic Resources	27 (3H, 23M, 1L)	33 (3H, 19M, 11L)	24
Noise	50 (8H, 14M, 28L)	12 (5M, 7L)	25
Human Health and Safety	NYR	NYR	NYR
Land Use	61 (32H, 29L)	19 (15H, 4L)	7

VEC	Number of RFFAs		
	Negative Effects	Positive Effects	No Change
Transportation and Traffic	17 (6M, 11L)	18 (1H, 7M, 10L)	52
Socioeconomic Resources	NYR	NYR	NYR
Cultural Resources	NYR	NYR	NYR
Recreation (see Note 4)	37 (10H, 19M, 8L)	31 (7H, 15M, 9L)	25

Codes: H = high importance, M = medium importance, L = low importance, U = uncertain, NA = not available at this time but will be developed later in 2003, NYR = a preliminary matrix has been prepared, however, it will be refined and reviewed later in 2003

Note 1: The totals of 54 and 27 each include one RFFA with both negative and positive effects and categorized as having a low importance.

Note 2: The totals of 51 and 28 each include five RFFAs with both negative and positive effects; the five RFFAs include three categorized as having high importance, and two as having medium importance.

Note 3: The totals of 42 and 27 each include three RFFAs having both negative and positive effects; the three include two categorized as having high importance and one as having medium importance.

Note 4: The totals of 37 and 31 each include seven RFFAs with both negative and positive effects; the seven include one categorized as having high importance, four as medium importance, and two as low importance.

Brief summary comments on the AER – Water Quality/Sediment Quality matrix will be used as an illustration. A total of 64 RFFAs were denoted as having effects, with 43 anticipated causing negative effects and 21 causing positive effects. The importance categories of the 64 RFFAs are listed in **Table A-11**. The negative effects are anticipated from construction activities that cause increased turbidity levels; from multiple activities and operational processes that may cause increased discharges of many types of pollutants; and from nonpoint sources such as runoff from urban, industrial and agricultural land uses. Beneficial effects are typically associated with RFFAs in the Regulatory Environment category; examples include the adoption of more stringent standards for environment media, pollutant source control, and the Phase 1 and 2 NPDES program. A key point relates to the multiple RFFAs (43) that are anticipated to cause negative effects on water and sediment quality. Further, there are implications of changes in water/sediment quality relative to other aquatic ecological resources such as fish, mussels, and macro-invertebrates. Summary comments on the other matrices are available in Exhibit B. As appropriate, each of the VEC-related chapters include summary information from their pertinent RFFA matrices.

A.4.3. Lessons Learned About the Completion of the RFFA Matrices

A number of lessons have been learned regarding the completion process for the 22 matrices; they include:

(1) Review of the definitions of various matrix terms is critical for each user prior to the initiation of completion work. Such definitions relate to categories of, and individual, RFFAs; and the classification codes for time period, occurrence probability, location on the River, and relative

importance. Further, frequent referrals to the definitions will be necessary as the completion work proceeds.

(2) Completion of a matrix for an individual single component VEC (e.g., air quality), or matrices for multiple subcomponents of a single VEC (e.g., terrestrial habitat, islands, wetlands, soils and geology, and floodplain hydrology within the riparian/floodplain ecological resources VEC) can be a complex task. The complexity is due to the need to address 87 RFFAs, to consider various features of each identified effect (whether positive or negative, or both; frequency; duration; area affected; other VECs affected; recoverability/reversibility; and relevant regulatory standards, criteria, or policies), and to rate the relative importance of each effect. Further, the aggregate tasks associated with the completion of 22 such matrices also add to the overall complexity.

TABLE A-11
Importance Categories for RFFAs in Relation to the Water Quality/Sediment Quality Subcomponent of the Aquatic Ecological Resources VEC

RFFA Importance Category	Negative Effects	Positive Effects
High	• Instream sand and gravel mining (BFA) • Coal utilities (BFA) • Other coal industries (BFA) • Industrial users, excluding coal-related (BFA)	• More stringent standards for environmental media (RE) • Pollutant source control (RE)
Medium	• L&D operation and maintenance (NIA) • Dry dams, other projects off mainstem (OCA) • Fleeting areas/barge storage (BFA) • Terminals (BFA) • Floodplain sand and gravel mining (BFA) • Agriculture (ABO) • WWTP discharges, industrial (ABO) • Stormwater discharges (ABO)	• Dry dams, other projects off mainstem (OCA) • ERP projects – 5 categories (OCA) • Phase 1 and 2 NPDES program (RE) • TMDLs (RE) • Effluent trading (RE) • Agricultural discharges (RE) • Environmental awareness education (RE)
Low	• Lock extensions/new locks/ replacement or rehabilitation (NIA) • Dam rehabilitation (NIA) • Channel dredging/dredged material disposal (OCA) • Navigation aids-construction and O&M (OCA) • Levees/floodwalls (OCA) • Channel modifications (OCA) • Recreation facilities-construction and O&M (OCA) • Port development (Sec.107) and maintenance dredging (OCA) • Pool maintenance (OCA) • Barge queuing (BFA) • Increased traffic (BFA) • Dispersed barge traffic (BFA)	• Non-structural navigation improvements (NIA) • Emergency streambank stabilization (OCA) • Modifications of Corps structures for environmental improvements (Sec.1135) (OCA) • Environmental restoration of aquatic ecosystems (Sec.206)(OCA) • Barge/tow tech/green design (BFA) • Hazardous waste sites (ABO) • Wetland mitigation banking (RE) • Pollution prevention (RE) • ORSANCO monitoring program (RE) • Spill response (RE) • Information and FOIA (RE)

RFFA Importance Category	Negative Effects	Positive Effects
	• Accidents/spills (BFA) • Coast Guard navigation aids-construction and O&M (BFA) • Limestone aggregates mining (BFA) • Hydropower on dams (BFA) • Recreation facilities-construction and O&M (BFA) • Floodplain development-residential (ABO) • Floodplain development-commercial (ABO) • Floodplain development-industrial (ABO) • Riverbed crossings (ABO) • Marina development and operation (ABO) • Boating (ABO) • PWCs (ABO) • Silviculture (ABO) • WWTP discharges-municipal (ABO) • Casinos (ABO) • Floods (ND) • Droughts (ND) • Farmland preservation (RE) • COE permitting programs (RE) • Small navigation projects (RE)	• ESA (Endangered Species Act) (RE) • Environmental sustainability practices (RE)
Notes: NIA = navigation investment actions OCA = other Corps actions BFA = "but for" actions ABO = actions by others ND = natural disasters RE = regulatory environment		

(3) Completion of a matrix can also be time-consuming. One reason is related to the above-noted complexity. Further, recording of "smart cell" notes related to the matrix cells is time-consuming. Finally, if a team approach is used, the discussions related to the pertinent cells can extend over considerable time periods.

(4) Several approaches can be used for matrix completion. For example, the matrices were initially completed using the following approaches: (a) an IWGC or CPTC discussed and completed a matrix; (b) a sub-set of an IWGC or CPTC either met together, or utilized a teleconference, to discuss and complete a matrix; the draft matrix was then provided to the other members of the IWGC or CPTC for review and comment; or (c) a subject matter expert from an IWGC or CPTC completed a matrix; the draft was then provided to other members of the IWGC or CPTC for review and comment. Following the initial completion of the matrices, they were subjected to an independent consistency review by the CPT. Then, the CPT prepared summaries of each matrix. One primary lesson learned from this process was that there is no single approach that is always better for an initial matrix completion. Further, to ensure inter-matrix and intra-matrix consistency, it is important to subject the completed matrices to internal and

independent review procedures in order to minimize the introduction of bias into the process.

(5) To facilitate a more efficient use of time in the completion of a matrix, it may be desirable to break the work into shorter segments. One way to do this would be to address complete categories of RFFAs during an allocated time period. Another approach for achieving time efficiency would be to assign effects ratings, as appropriate, to all RFFAs; this could be followed, at a later time, with the assignment of importance ratings for the RFFAs.

(6) A critical component of matrix completion is the recording of notes in the individualized "smart cells". These notes provide the basic logic for the column related to the effects of the RFFA on the VEC (or the subcomponent of the VEC). Such information related to the types of effects has been used in the preparation of chapters on the VECs and their related subcomponents. Further, notes are also important for the "smart cells" in the column related to the relative importance of the RFFA. This information is fundamental to describing the logic for the importance categories of high, medium, and low. The results were used in "downstream scoping" of (selecting and prioritizing) the RFFAs addressed in the VEC-related chapters. Finally, it is recognized that the effects of multiple RFFAs on the VEC (or subcomponent) may be a result of similar activities (e.g., construction phase runoff), thus similar notes could apply to multiple RFFAs.

(7) It is important that the RFFA matrices be seen as "tools" to facilitate one feature of the CEA process. However, users of the matrices should not become "slaves" thereof. For example, larger scale ecological processes and/or smaller scale concerns may not be given appropriate attention via the delineation of specific VECs and related subcomponents. However, issues "outside the box" can be addressed, with this being accomplished by supplementary notes and observations, as appropriate. This lesson is based on the premise that a "tool" should lead the users in a given direction, but their associated thinking should not be constrained.

(8) Systematic work on the completion of an RFFA matrix can facilitate creative thinking by the users. Such thinking can be prompted by discussions related to effects or importance ratings, or both. Illustrations of where creative thinking is needed include the identification of linkages between VECs or subcomponents; and the recognition of similarities between effects of different RFFAs, and the possibility for using common mitigation measures.

(9) While an RFFA matrix can be a valuable tool for analysis (breaking a complex issue into parts and examining the parts), it also needs a synthesis feature to bring the parts into an overall perspective. Accordingly, a completed matrix needs to be summarized in order to present a holistic perspective, and to make the results comparative and useable.

A.4.4 Lessons Learned About the Value and Further Uses of RFFA Matrices

The following lessons have been identified relative to the value and further uses of the RFFA matrices in this CEA study:

(1) The RFFA matrix is a valuable tool that facilitated a systematic process for considering and evaluating RFFAs in a CEA study. For example, in traditional project-level impact studies, there is a tendency to consider the effects of the project in isolation. CEA requires the consideration of the effects of multiple past, present, and future actions. RFFA matrices force the users to consider multiple future actions that may impact a given VEC or subcomponents. Further, completed RFFA matrices provide a documented basis for "scoping" RFFAs and determining which should be addressed in a more detailed manner.

(2) Information extracted from completed RFFAs can be utilized to summarize a number of key points related to a CEA study. Examples of such information include expected time periods wherein given RFFAs are expected to occur; their occurrence probabilities; the locations or settings on or along the River wherein the given RFFAs are expected to occur; the RFFAs with anticipated negative effects, positive effects, and combinations thereof; and the importance categories for the RFFAs. Further, a composite picture of the effects of a given RFFA across all VECs was drawn from an analysis of each of the 22 matrices.

(3) The RFFA matrix was used as an initial step in delineating the relative contributions of individual RFFAs to the overall cumulative effects. For example, RFFAs rated as having high importance would be expected to contribute more to the cumulative effects on a VEC than RFFAs rated as low importance. In certain cases, more detailed data gathering and analysis efforts were conducted to quantify (approximate) the relative contributions of an RFFA to the cumulative effects on a VEC.

(4) The majority of the RFFAs in the first five categories (4 in navigation investment actions, 13 in other Corps actions, 19 in "but for" actions, 26 in actions by others, and 4 in natural disasters) represent continuations of past and present actions. However, from an historical perspective, different actions were initiated in different time periods in the past. Therefore, effects information from the completed RFFA matrices were applied, as appropriate, to historical time periods and present actions, and utilized to qualitatively summarize the effects of past and current actions on the VECs.

(5) Information from the RFFA matrices can be used to examine the relationship between cumulative effects on a VEC or subcomponent thereof, and the ES of that resource, ecosystem, or human community. As utilized herein, ES refers to "a synergistic process whereby environmental and economic considerations are effectively balanced through the life cycle of project planning, design, construction, operation and maintenance to improve the quality of life for present and future generations" (U.S. Army Corps of Engineers, 2002). The AES approach was briefly described in

conjunction with Step 5. An example for this third method is in the following section of this chapter.

(6) Necessary monitoring programs can be developed for "not sustainable" or "marginally sustainable" VECs or subcomponents determined to have significant cumulative effects. Such monitoring can be focused on the indicators and the potential contributions of RFFAs identified as being in the high and medium importance categories. Further, mitigation measures can be identified for key RFFAs, thus forming an initial basis for interagency discussions related to appropriate mitigation and adaptive management strategies for specific VECs.

(7) The following generalized steps can be used to develop RFFA matrices for any CEA study:

- Develop a RFFA definition.
- Identify RFFAs based on a diversity of approaches, including the scoping process, review of planning documents, discussions with multiple public sector agencies and private sector groups, solicitation of information from a study steering committee, and use of the Internet.
- Categorize the RFFAs as appropriate.
- Develop matrices that relate the RFFAs to potentially affected resources, ecosystems, and human communities (referred to herein as VECs and subcomponents thereof). Include appropriate RFFA codes within the matrices that delineate the time period and probability of their occurrence, and their location, effects, and relative importance.
- Complete the matrices via assignment of the codes and the inclusion of the rationale for each assignment.
- Summarize the results of the completed matrices and use them as appropriate in the CEA study documentation process.
- Develop "downstream uses" of the RFFA matrices as appropriate; examples include relating cumulative effects to environmental sustainability, identifying and planning mitigation measures and adaptive management, and implementing a focused cumulative effects monitoring program.

A.5 ANALYSIS OF ENVIRONMENTAL SUSTAINABILITY

The third method relates to a qualitative approach to integrate information on past, present, and future actions into an analysis of their effects on Environmental Sustainability (ES). This method was used for all of the VECs and their subcomponents, with the results described in the individual pertinent chapters. The findings were then used as a basis for applying the ES needs approach (the fourth method). This section includes an example of the application of the Aquatic Environmental Sustainability (AES) approach to the water quality and sediment quality VEC (see Chapter 3). The second subsection enumerates some lessons learned from the applications of the AES method.

A.5.1 Example of AES Approach

To illustrate the AES approach as described in Step 5 above, the water quality subcomponent of the aquatic ecological resources VEC will be used as an example. The first part of the AES identified four common effects of multiple High and Medium importance actions. As shown in **Table A-12**, they include 8 actions causing turbidity and sedimentation, 5 actions contributing to point source pollution, 4 actions contributing to nonpoint source pollution, and 8 actions contributing to pollution reduction. Examples of actions from each common effects category include channel dredging/dredged material disposal and instream sand and gravel mining (turbidity and sedimentation), coal and related industries and marina operation (point source pollution), stormwater discharges and agriculture (nonpoint source pollution), and more stringent quality standards for environmental media and pollutant source control (pollution reduction).

Table A-12
Actions Causing Four Common Effects on Water Quality

Effects	Actions
Turbidity and Sedimentation	• Channel dredging/dredged material disposal (H) • Instream sand and gravel mining (H) • Lock and dam maintenance and operation (M) • Port development and maintenance dredging (M) • Terminals and multimodal sites (M) • Fleeting areas/barge storage (M) • Increased traffic (M) • Marina development and operation (M)
Point Source Pollution	• Coal and other related industries (H) • Industrial river users, excluding coal-related (H) • Industrial discharges (M) • Accidents/spills (M) • Marina operation (M)
Nonpoint Source Pollution	• Stormwater discharges (M) • Agriculture (M) • Industrial development (M) • Floodplain sand and gravel mining (M)

Effects	Actions
Pollution Reduction	• More stringent quality standards for environmental media (H) • Pollutant source control (H) • ERP projects (M) • Phase 1 and 2 NPDES program (M) • TMDLs (M) • Effluent trading (M) • Control of agricultural resources (M) • Environmental awareness education (M)
(H) = high importance (M) = medium importance	

Six indicators of ES were identified and pertinent historical to current information on them has been summarized in Chapter 3. Regarding their relevance for ES, the following rationale is appropriate:

- measures of key water quality parameters

(1) dissolved oxygen – related to the total organic loading from point and nonpoint sources at specific locations along the river; can also be used as a threshold indicator since the DO standard is 5.0 to 6.5 mg/l, depending upon several conditions

(2) fecal coliforms – related to fecal matter contamination from humans or other animals, whether from point or nonpoint sources at specific locations along the river; can also be used as a threshold indicator since the standard is 2000 fecal coliforms/100 ml

(3) turbidity and total suspended solids – related to solid material which can be attributed to point and nonpoint sources at specific locations along the river; can originate from both man-made wastewater discharges and natural erosional processes; no specific numerical standards exist for the Ohio River

(4) nutrients such as nitrogen and phosphorus – related to the total nutrient loading from point and nonpoint sources at specific locations along the river; the nitrogen standard is 10 mg/l (for nitrite plus nitrate nitrogen); no standard has been adopted for phosphorus

- level of conformance with state and federal water quality standards, including attainment of permissible use designations – water quality standards are based on various use designations, with the level of conformance representing a composite indicator of a sustainable aquatic ecological resource

- TMDL implementation – the TMDL (total maximum daily load) program is for specific water quality parameters which may reflect an "overloaded" situation related to point and nonpoint sources at specific locations; implementation of the program reflects a coordinated effort to achieve appropriate water quality standards and promote a sustainable ecological resource

- effectiveness of specific point source control and nonpoint source control programs – such programs are focused on reducing pollutant discharges into the river, and thus they promote a more sustainable aquatic ecological resource

- ability to sustain diverse, healthy populations of aquatic organisms – an aquatic system which attains water quality standards while minimizing the effects of "legacy contaminated sediments" should sustain diverse populations of various organisms; further, it should attain permissible use designations

- effectiveness of spill response, monitoring programs, and related precautionary measures – these represent both direct and indirect programs which are focused on more effective management of water and sediment quality, and thus the promotion of a sustainable aquatic ecological resource

For the purposes of AES, the six indicators were grouped into three tiers as follows:

- first tier – "scientific measures of quality" -- water quality parameters (DO, fecal coliform bacteria, turbidity, total suspended solids, N and P); and conformance with water quality standards

- second tier – "positive actions related to source control" -- point source control and nonpoint source control programs; TMDL implementation; and spill response, monitoring programs, and related precautionary measures

- third tier – "composite indicators of aquatic ecosystem sustainability"; this includes two measures developed from several indicators -- attainment of permissible use designations; and sustain diverse, healthy populations of aquatic organisms

Finally, the indicators and tiers were displayed into four tables (not included herein, but found in Chapter 3), with each table coinciding with the four groups of actions with common effects. Qualitative discussions of each table were then presented. For example, turbidity and sedimentation represent historical water quality concerns in the Ohio River, even with the absence of specific standards. Control programs for municipal and industrial point sources have been implemented within the last several decades, while similar programs for nonpoint sources are largely in their first decade. Increased control programs, including operational measures, are expected in the future for channel dredging/dredged material disposal, and port and marine development and operation. Implementation of a TMDL program for turbidity could occur in localized reaches of the river. Further, spill-related programs and precautionary measures are expected to reduce accidental releases. As a result of these current and anticipated future source control efforts, for turbidity and sedimentation it is expected that permissible use designations will be more easily attained, thus increasing the sustainability of diverse populations of aquatic organisms.

Regarding point source pollution, of particular concern are industrial water users and dischargers who may introduce diverse chemicals and bacteria into the river. Existing point and nonpoint source control programs have already led to reductions in industrial discharges, thus increasing the possibilities for achieving conformance with water quality standards. Future source control programs may become more stringent, and TMDL

requirements could be implemented for specific industrial pollutants in certain river reaches. Also, spill prevention and response programs are expected to reduce accidental point source pollution. As a result of these current and possible future point source control efforts, it is anticipated that additional river reaches will attain their respective permissible use designations, and the river itself will be able to sustain more diverse populations of aquatic organisms.

Nonpoint source control programs are being currently implemented for stormwater discharges from urban areas, and for runoff waters from industrial areas. Source control programs related to floodplain sand and gravel mining, as well as agriculture, are anticipated, although the specific requirements and their possible effectiveness are largely unknown. However, when considering the background of a minimal historical emphasis on controlling nonpoint source pollution, it does appear that the current efforts, when coupled with possible future emphases, are and will improve the ES of the aquatic ecosystem.

Finally, several of the 8 RFFAs expected to contribute to pollution reduction in the river represent continuations of existing pollution reduction efforts. Accordingly, the sustainability of the aquatic ecosystem is expected to improve over time

Regarding the three categories for ES of water quality, the following specific definitions were used (similarly structured definitions were used for each of the pertinent VECs and their subcomponents):

- Not sustainable -- the composite conditions for the selected indicators do not reflect conditions that would facilitate attainment of permissible use designations, nor would they sustain diverse populations of aquatic organisms.

- Marginally sustainable -- the composite conditions for the selected indicators are such that the attainment of permissible use designations is accomplished for the majority, but not all, of the river miles in the mainstem, and diverse populations of aquatic organisms are occurring along the majority of the River; however, the conditions of the indicators are somewhat tenuous both in location and likelihood of occurrences.

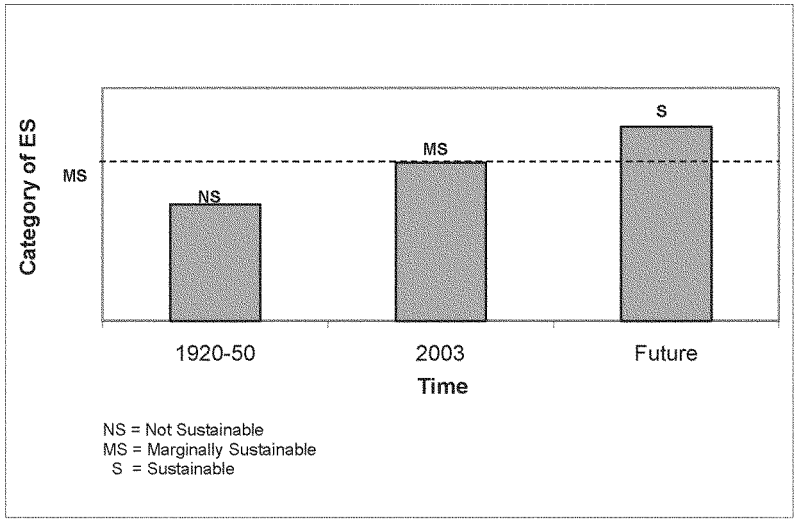
- Sustainable -- the composite conditions for the selected indicators are such that the attainment of permissible use designations is accomplished for essentially all of the river miles in the mainstem, and diverse populations of aquatic organisms are occurring along the majority of the River; further, the conditions of the indicators exceed regulatory thresholds and various governmental programs are in place to control point and nonpoint pollution sources and to emphasize pollution reduction.

Based upon the historical to current affected environment conditions described in Chapter 3, the multiple actions and effects, the tiers of indicators, and the ES categories, the ES of the water quality of the mainstem of the Ohio River can be characterized and depicted in **Figure A-1** as follows:

- In the time period prior to 1920, and continuing up to about 1950, the water quality of the mainstem was in a degraded state characterized by low DO concentrations, low pH levels in the upper River, high bacterial contamination, high nitrogen

concentrations, and remobilization of potentially toxic chemicals that had become associated with River sediments. Essentially no pollution reductions or controls programs, or regulatory programs, were in place during this period. Further, declines in the diversity and health of fish communities in the mainstem also were experienced (see the chapter on fish resources). Accordingly, the ES of the water quality VEC was classified as "not sustainable". Primary contributors to these conditions were the largely untreated and uncontrolled point and nonpoint pollutant discharges from growing municipalities and various types of industries and land uses along the River.

FIGURE A-1
ES of Water Quality



- Due to the programs of ORSANCO, and the requirements of the Federal Water Pollution Control Act (and the amended Clean Water Act), the water quality of the River has shown a steady improvement in recent decades. For example, DO concentrations are typically above the 5.0 mg/L standard, pH levels are between the 7.0 to 9.0 standard, and nitrogen concentrations meet current water quality criteria. However, bacterial contamination primarily associated with NPS pollution is still problematic downstream of major urban areas. Further, legacy "contaminated sediments" are a concern in the upper River along with fish consumption advisories throughout the mainstem. In contrast, the results of algae (plankton) and aquatic macroinvertebrate biological surveys in the five most recent decades have demonstrated steady improvements in these aquatic ecological resources, with the improvements paralleling water quality improvements. Regarding the attainment of permissible use designations, as of 2001, 974 of 981 miles (99.3%) of the mainstem are "fully supporting" aquatic life, and 970.5 miles (98.9%) are "fully supporting" public water supply use. None of the mainstem was "fully supporting" fish consumption due to restricted or no consumption advisories along its total length. For contact recreation use, 804.3 miles (82.0%) are "fully supporting" this

use. Finally, implementation of NPDES permit programs for municipalities, industries, and stormwater has led to the reduction of discharges into the mainstem. Initiatives for increasing the use of BMPs have also been established. Also, information from the fish resources chapter has indicated that the diversity and health of fish communities along the mainstem has considerably improved from the 1920 to 1950 period. Accordingly, at this time (2004), although there are many positive signs, the ES of the water quality VEC was classified as "marginally sustainable". The primary concerns are associated with bacterial contamination and chemical remobilization from legacy-contaminated sediments.

- Regarding the future, it is expected that the water quality of the Ohio River mainstem will further improve as a result of the continuation of source control and other pollution reduction programs, and the implementation of the ERP and other remediation efforts. Therefore, it is anticipated that the ES of the water quality VEC will achieve a "sustainable" condition. However, this characterization should not bring complacency; rather, vigilant efforts are still needed to continue effective water quality and aquatic ecological monitoring and management efforts. In this regard, it may be desirable to plan and implement source monitoring programs for selected RFFAs (actions) considered being of high importance relative to cumulative effects. Further, surveys for legacy-contaminated sediments are needed along with site-targeted efforts to reduce bacterial emissions from CSOs. Furthermore, several actions are expected to be beneficial to the water quality resource in the future. For example, adverse impacts related to barge operation (e.g. queuing, dispersed traffic) will be alleviated to some extent 1) through implementation of nonstructural navigation improvements and 2) through technological improvements related to communications and more environmentally-advanced barge design. Activities that support commercial navigation (e.g. port development and maintenance dredging) will continue to be scrutinized by both regulatory agencies and NGOs and may be more strictly regulated. Land disposal of in-stream dredged materials, for example, may become more common than is practiced today. Some development activity may revive or renovate underused urban space or industrial brownfields areas, with possible long-term water quality benefits related to surface and groundwater clean up. Much development activity, however, will involve conversion of existing floodplain lands (e.g. farmland, riparian woods, and wetlands) that now afford habitat protection, open space and ecosystems values. Once converted, such lands are unlikely to revert to their former more natural states. Increasing emphasis on pollution prevention, erosion control BMPs and implementation of the Phase 1 and 2 NPDES programs could counteract some adverse impacts, particularly in more urban areas. In general, several regulatory initiatives in recent years, including TMDL development, the national CSO policy, and Phase 1 and 2 programs should measurably improve water and sediment quality, but, at this time, it is not possible to predict the magnitudes of their beneficial effects.

A.5.2 Lessons Learned About the AES Approach

The lessons learned regarding the application of the AES approach include the following:

- The approach encourages the user to think about the connections between multiple actions and indicators in both a relative and holistic manner, thus encouraging the synthesis of a large body of information.

- The approach could be strengthened with quantitative information on each action, indicator, and tiers of indicators; however, in the absence of time-related information on each part, a qualitative discussion of the connections can still be useful.

- The structured framework of the approach can be useful for identifying current and future monitoring and mitigation needs, and for planning adaptive management programs, as appropriate.

- One principle of CEA is related to considering the total effects of the direct and indirect effects of past, present, and future actions (Council on Environmental Quality, 1997). The AES approach promotes such a total effects perspective.

- Application of the AES approach to VECs and their subcomponents provides an appropriate focus on the Rs, Es, and HCs of particular concern. This is another fundamental principle of CEA (Council on Environmental Quality, 1997).

A.6 ENVIRONMENTAL SUSTAINABILITY NEEDS

The ES needs (ESN) approach is the fourth method used in this CEA study. The ESN was not applied uniformly to all VECs and their subcomponents; rather, it was applied to the two VECs that were determined to have been subjected to the greatest cumulative effects, and which need the most attention regarding both current and future environmental management. The two VECs were aquatic ecological resources (including water quality and sediment quality, mussel resources, and fish resources) and riparian/floodplain ecological resources. Chapters 3 through 7 herein address these VECs and their subcomponents. The first subsection herein describes a group process that was used to identify, prioritize, and summarize ES needs for aquatic ecological resources. Exhibit D provides details on the group process and findings. A similar process is planned for the riparian/floodplain ecological resources VEC.

The ESN also includes the consideration of an adaptive management program for the two VECs and their subcomponents. Basic information for an adaptive management program is included in the second subsection. Finally, another consideration is related to institutional authorities and policies for mitigating historic and future actions that have damaged the VECs, thus the last subsection summarizes such information for the Corps.

Because the issue of ESN was beyond the original scope of this CEA study, it should be recognized that the ESN approach is still a "work-in-progress". Additional planning efforts would be required to formalize these findings.

A.6.1 Example of Group Process to Identify ES Needs

To illustrate the ESN approach as mentioned in Step 10 above, the aquatic ecological resources VEC will be used as an example. This VEC includes three subcomponents

consisting of water quality, mussels, and fish. The approach, which is still in progress, consists of the following steps:

- Identification of an Aquatic Sustainability Group consisting of selected members of the IWG; other regional experts from universities, state agencies, and industry; and the Corps' CPT.

- Conducting a one-day "brainstorming meeting" of the Group, and documentation of the central themes and ideas. Advance instructions provided to the Group included the following items:

  (1) Accept that the system is highly modified and will remain so (i.e., it is not reasonable to return the River and floodplain to predevelopment conditions; however, the system is amenable to further modifications that may affect the resource either positively or negatively).

  (2) For now think only about the aquatic ecological resources. Do not worry about who will be responsible for any sustainability actions, who will pay for them, or when they will happen.

  (3) Be prepared to address the following questions:
  "What do we want the resources to look like?"
  "What needs to happen to attain this vision of the Ohio River?"
  "What are possible indicators of environmental sustainability?"

- Summarization of the responses and feedback to the Group for clarification and expansion, as appropriate.

- Prioritization of the responses to the above three questions by the Group.

- Formulation of alternatives and interagency collaborative strategies to improve the long-term sustainability of aquatic ecological resources of the Ohio River. These alternatives and strategies are being developed and will be included in the SIP/PEIS.

The process used to develop ES alternatives follows closely the general principles for ecological management defined by the Interagency Ecosystem Management Task Force, and summarized in the next sub-section (Keiter and Adler, 1998).

A.6.2 Ecosystem Adaptive Management

An emerging theme for strategic-level impact studies is the use of ecosystem management approaches to address larger-scale issues that may involve both policy and scientific uncertainties. Accordingly, the federal government is encouraging the implementation of ecosystem management approaches within and among federal agencies and among federal, state, and local agencies. Ecosystem (ecological) management includes the analysis of both the elements and the interrelationships involved in maintaining ecological integrity (Council on Environmental Quality, 1993). Such management should use a local-to-regional perspective that considers impacts at the

appropriate scale within the context of the entire ecosystem. To facilitate the implementation, the Interagency Ecosystem Management Task Force was formed in the mid-1990s. The work of this Task Force and other entities and individuals has been instrumental in defining the following general principles for ecological management (Keiter and Adler, 1998):

- Common ecological management goals should be socially defined through a collaborative vision process that involves all interested participants and that incorporates ecological, economic, and social considerations.

- Given that most ecosystems and watersheds transcend conventional geopolitical boundaries, ecological management requires coordination among federal, state, tribal, and local governmental entities as well as collaboration with other interested parties.

- Ecological management policies and decisions should be based upon integrated and comprehensive scientific information that addresses multiple rather than single resources.

- Ecological management seeks to maintain and restore biodiversity and ecosystem integrity.

- Ecological management involves management at large spatial and temporal scales that correspond to ecosystems and watersheds.

- Given the finite nature of public funds and other resources, ecological management enables agencies to engage in careful targeting to select achievable solutions and to allocate resources efficiently.

- Ecological management requires an iterative, adaptive management approach to account for changing goals and values and new scientific information concerning ecological conditions.

Adaptive management refers to a relatively new concept that recognizes that scientific uncertainties and unforeseen environmental changes are inevitable when various plans, programs, or policies are implemented in particular environmental settings. Accordingly, the application of the concept in environmental management entails (National Research Council, 2002):

> ..."the use of carefully designed and monitored experiments, based on input from scientists, managers, and citizens, as opportunities to maintain or restore ecological resilience and to learn more about ecosystems. These actions are monitored for scientific findings to help improve understanding of how policy decisions affect ecosystems. Findings from ecosystem monitoring are then to be used to appropriately adjust management policies. Adaptive management requires that clear goals and desired outcomes be established so that progress toward desired future conditions can be assured."

Adaptive management has been applied, or is being considered for application, in environmental management efforts related to several large-scale water resources projects and programs. For example, it is included in the Comprehensive Everglades Restoration Plan in Florida, the Glen Canyon Dam in Arizona, and the Upper Mississippi River Basin navigation study in the Midwest; and it has been proposed for the Missouri River Basin ecosystem management program. Further, the concept will be incorporated in the SIP/PEIS for the ORMSS.

A.6.2.1 Elements in an Adaptive Management Program

The key elements associated with an adaptive management program for the ORMSS include, but are not limited to, the following:

- The assemblage of information on the historical and current conditions of key indicators for environmental resources that are potentially subjected to impacts from a plan, program, or project; and the quantitative prediction or qualitative description of these anticipated impacts, along with impacts from other past, present, and reasonably foreseeable future actions (i.e., the cumulative effects), on the key indicators.

- A scientifically-designed monitoring program focused on measuring changes in key indicators of environmental resources subjected to potential cumulative effects.

- A strategic framework that includes periodic evaluations of the implementation of features of the SIP, the monitoring data and other related policy information, and decision-making, as appropriate, relative to adapting management policies or measures for the environmental resources of concern.

- Collaborative long-term agreements among pertinent federal, state, tribal, and local environmental agencies; and a program steering committee comprised of representatives from these agencies.

- Adequate budgetary and personnel resources.

- A peer group of advisors with expertise in public policy analyses, the planning and conduction of environmental monitoring and research, and environmental decision-making.

Each of these elements will be considered, as appropriate, in the adaptive management program within the ORMSS. As suggested, a key feature of adaptive management is the planning and implementation of monitoring programs.

A.6.2.2 Monitoring Planning as a Basis for Adaptive Management

Sadler and Davies (1988) describe three types of environmental monitoring which might be associated with the life cycle of a plan; for example, the SIP in this case. These include baseline (current conditions) monitoring, effects or impact monitoring, and compliance monitoring. Baseline monitoring is the measurement of environmental variables during a representative pre-project or pre-plan period to determine existing

conditions, ranges of variation, and processes of change. Effects or impact monitoring involves the measurement of environmental variables during construction and operation of one to several projects to determine changes that may have been caused, and to develop or evaluate mitigation measures. Finally, compliance monitoring takes the form of periodic sampling and/or continuous measurement of levels of waste discharge, noise, or similar emission, to ensure that conditions are observed and standards are met. It could also include the auditing of compliance with regulatory permit programs of the USEPA, the Corps, and the involved states. Pre-PEIS monitoring includes baseline monitoring, while post-PEIS monitoring encompasses effects or impact monitoring, and/or compliance monitoring. All three types of monitoring should be included in an adaptive management program.

Careful planning and implementation of a monitoring program is necessary for meeting the various purposes of monitoring. Three considerations are important in planning monitoring programs in the United States. First, there is an abundance of environmental monitoring data routinely collected by various governmental agencies and the private sector. This data needs to be identified, aggregated, and interpreted since information is often compiled but never interpreted relative to the quality of the environment being monitored. Second, environmental monitoring programs are expensive to plan and implement. Every effort should be made to use or modify extant monitoring programs. Third, owing to overlapping environmental management and monitoring responsibilities of many local, state, and federal governmental agencies, it will be necessary to carefully coordinate environmental monitoring planning with several agencies.

To illustrate the scientific considerations that may be involved in planning a monitoring program, a generic seven-step conceptual framework for developing a plan for biological and ecological monitoring will be highlighted (Spellerberg, 1991). The framework can be adapted to the monitoring of environmental media, and socioeconomic and/or social impacts. The first step would be to define the monitoring objectives. In many monitoring schemes, the objectives are either not stated or are so complex that they become meaningless (Spellerberg, 1991). The second step would be to determine the spatial locations where the monitoring will take place. The third step would be to make sure the data collected are documented for future use. When monitoring programs extend over long periods of time, such as for the SIP, professionals working on the adaptive management program will change. So the need arises for methods to assure the retention of such data, which should be accessible and understandable to successive professionals. The fourth step entails various arrangements for data collection and storage. The success of a monitoring program depends not only on good planning and logistical support, but also on coordination with other related programs.

The fifth step involves the process of selecting the variables (indicators) to be measured. The ideal variable and process would have a wholly ecological basis but logistic limitations (finances, time and effort) may override these considerations. Due to such logistic limitations, methods for collection of data from the field or assemblage of data from other sources should therefore be considered along with the choice of indicators. Monitoring data can be aggregated into pertinent indices to reflect the composite quality of different environmental categories. For example, several indices for the biological environment have been developed; one example is an Index of Biotic Integrity (IBI) for stream fish assemblages. Chapter 6 herein refers to an Ohio River Fish Index (ORFiN).

The sixth step would involve the preliminary data gathering and baseline surveys. Before biological monitoring should start, biological information from published sources or preliminary field studies should be assembled. Finally, the seventh step involves the analysis and presentation of the data. Considerations of who will use the data, to make recommendations, should be reviewed when the form of data presentation is selected (Spellerberg, 1991). For an adaptive management program, it is anticipated that the program steering committee will use the information to adapt management efforts, as appropriate.

A.7 INSTITUTIONAL CONSIDERATIONS FOR MITIGATION BY THE CORPS

As part of this CEA study, a study was conducted to review and summarize the Corps' statutory authorities, policies, regulations, guidance, and practices associated with mitigation of historical environmental damages from the construction, operation, and maintenance of Corps projects, and/or damages from projects and actions by others (governmental or private); and to review and summarize similar institutional information related to the necessity for mitigation of the potential environmental damages from projects, plans, and/or programs under current planning and development (Canter, 2003). Mitigation of historical damages from Corps actions can be perceived as "mitigation for previous effects", while mitigation of potential damages can be classified as "mitigation for future effects". Mitigation for previous effects includes "ecosystem restoration" projects and activities. The focus of this study was on mitigation related to damages to the "natural environment", thus, it encompasses physical, chemical, and biological characteristics as reflected by mitigation for effects on streambank erosion, water quality, fish, and wildlife; in other words, the effects have occurred or are anticipated to occur on aquatic and riparian/floodplain ecological resources.

The major effort associated with this study consisted of the review of a large number of Corps' policies, regulations, pamphlets, and supporting information related to ecosystem restoration (mitigation for previous effects), mitigation (mitigation for future effects), and either mitigation (for previous or future effects) for water quality management, or streambank erosion. Attention was directed to specific statutory authorities, policies, and requirements associated with mitigation for historical or anticipated environmental damages. Six subsections are included herein. In the first, the institutional context for this study is framed. The second subsection summarizes the general review of key laws, regulations, and executive orders that are related to ecosystem restoration and mitigation. The third subsection is specifically focused on ecosystem restoration authorities and policies, while the fourth does similarly for mitigation. The fifth subsection highlights the laws and policies related to water quality management and streambank erosion. The last subsection delineates the overall conclusions.

A.7.1 Findings on Institutional Context

There is an evolving institutional context regarding historical and future mitigation for Corps plans, programs, and projects. Of major significance are the EOPs issued by the Chief of Engineers in March, 2002; these EOPs are to be included in the Corps planning process. Two specific examples are the goals of achieving ES (EOP #1), and assessing and

mitigating cumulative impacts (EOP #5). These two goals are inclusive of both mitigation for previous or future effects. Further, it is significant that all seven EOPs served as the foundation for EC 1105-2-404 (May, 2003) and ER 200-1-5 (October, 2003). The EC and ER include numerous statements that support the creative integration of ES and other EOPs in the formulation and analysis of water resources plans, including plans focused on both addressing primary problems (e.g., flood damage reduction, navigation, or ecosystem restoration) and secondary problems which provide opportunity for enhanced environmental management.

The Corps' 2002 draft strategic plan for the Civil Works program contains considerable information on, and commitments to, both mitigation for previous or future effects (U.S. Army Corps of Engineers, 2002b). Both types of mitigation are directly mentioned, or inferred, in the Civil Works mission statement, two of the five identified challenges, and several goals and strategic objectives. Full utilization of the existing authorities of the Corps will facilitate the planning and implementation of appropriate mitigation measures for previous or future effects.

Based upon these current Corps activities, the following key conclusions regarding the institutional context for this study are relevant:

- ES is increasingly becoming a key issue in the Corps' development of water resources plans, programs, and projects; in fact, the Corps is taking a leadership role among governmental agencies regarding the promotion of ES throughout its planning and operational missions.

- There are numerous challenges when incorporating ES in water resources planning; they include, but are not limited to, the need to consider past, present, and future cumulative effects on significant natural and environmental resources; the potential need to mitigate for both previous and future effects to enhance the sustainability of significant resources; and the need for multi-agency collaborative efforts to monitor and promote ES on a continuing basis.

- Referrals to "restoring" natural and environmental resources infer that the Corps is not the sole cause of historical degradation; rather, the implications are that such degradation may have been the result of multiple causes, including past actions by the Corps, other governmental entities, and private sector developments.

A.7.2 Findings on Statutory and Other Authorities

The current statutory authority for mitigation of both previous and future effects for Corps plans, programs, and projects is contained in selected sections of four Water Resources Development Acts -- WRDAs (Sections 904, 906, 907, and 1135 of WRDA 1986, Sections 306 and 307 of WRDA 1990, Section 204 of WRDA 1992, and Sections 206 and 207 of WRDA 1996). Commonly used words in the selected sections include "protection" and "restoration", with the former typically denoting mitigation for future effects, and the latter mitigation for previous effects. However, it should be noted that protection could also be a feature of mitigation for previous effects. Mitigation of Corps contributions to historical degradation of natural and environmental resources is specifically included in some of the above sections. Navigation-specific statutory authority related to lock and dam replacement is currently based on Section 205 of WRDA

1992 (funding of major rehabilitation modifications to enhance operating efficiency beyond the original project design). Specific replacement or rehabilitation projects would currently be subject to the requirements of NEPA; therefore, mitigation for future effects, as appropriate, would be considered. Correction of shoreline damages resulting from existing Federal navigation projects is addressed in Section 111 of the RHA of 1968, as amended by Section 940 of WRDA 1986. Such corrections are specific examples of mitigation for previous effects for one type of environmental effect of navigation projects; i.e., shoreline erosion and damage.

Finally, a major law that is intertwined with water resources planning is the FWCA of 1958. This law emphasizes that fish and wildlife resources are to be conserved in the planning and implementation of water resources development projects. Several sections of the FWCA incorporate provisions whereby mitigation for either previous or future effects, or both, should be included in new or modified projects. Another important feature of the FWCA is the requirement that active consultation and coordination occurs between the Corps and the USFWS and/or the NMFS.

Based upon the laws above, along with related EOs (Executive Orders), ERs, and PGLs (Planning Guidance Letters), the following conclusions regarding statutory and other authorities can be noted:

- The Corps has several statutory authorities under which the planning and implementation of mitigation measures for both previous and future effects can be accomplished in association with continuing and new projects and their operation.

- The FWCA is a particularly important law related to water resources planning; it encompasses mitigation for both previous and future impacts on fish and wildlife resources. Further, it requires active coordination between the Corps and the USFWS and/or NMFS regarding mitigation needs and the implementation of mitigation measures.

- Two key EOs which encompass both types of mitigation include the protection of wetlands (EO 11990), and floodplain management (EO 11988). Both wetlands and important floodplains and riparian zones are in the geographical scope of the ORMSS. Further, information related to both types of mitigation can be found in selected ERs (ER 1165-2-26, and ER 1130-2-540) and PGLs (PGL Nos. 46, 49, and 56) of the Corps.

A.7.3 Findings on Ecosystem Restoration

Stated policies regarding the ecosystem restoration mission of the Corps are found in ER 1105-2-100 (Planning Guidance Notebook), ER 1165-2-501 (Civil Works ecosystem restoration), and EP 1165-2-502 (ecosystem restoration – supporting policy information). While the focus of restoration can be characterized as mitigation for previous effects, some features of an actual restoration plan can include protection against future degradation, thus it can also include mitigation elements that address future effects.

Specific authorities for ecosystem restoration are divided into three categories. First, Congressionally authorized studies and provisions in existing laws can be used. One example of a law in the first category is the ORMSS, which resulted in authorization of an

Ecosystem Restoration Program specific to the Ohio River and floodplain. The second category encompasses programmatic authorities, including Section 1135 of WRDA 1986, as amended (project modifications for improvement of the environment); Section 206 of WRDA 1996 (aquatic ecosystem restoration); Sections 204 of WRDA 1992, as amended (beneficial uses of dredged material); and Section 312 of WRDA 1990, as amended (environmental dredging). The third category involves the use of existing operation and maintenance authorities for specific projects. Section 216 of the 1970 River and Harbor and Flood Control Act allows review of completed projects or their operation due to significantly changed physical or economic conditions or for improving the quality of the environment in the overall public interest. Two common themes arise from the above three categories of ecosystem restoration authorities. First, cost sharing is typically required for ecosystem restoration projects. Second, such projects must be environmentally and economically justified via the application of an incremental cost analysis procedure applied to the anticipated environmental benefits and associated costs of various measures comprising the restoration action.

Based upon this information, the following conclusions regarding ecosystem restoration (mitigation for previous effects) can be drawn:

- Ecosystem restoration can and often does include measures related to reducing historical degradation of resources (mitigation for previous effects) as well as measures that are protective against future degradation of those resources (mitigation for future effects).

- Three categories of authorities can be used by the Corps to study, plan, design, and implement ecosystem restoration projects. They include Congressionally authorized studies and provisions in existing laws, programmatic authorities within specific sections of five recent WRDAs, and existing operation and maintenance authorities for specific projects.

- The Corps can engage in the planning and implementation of ecosystem restoration projects where previous Corps projects or actions are the sole contributor to degraded resources, or where they are partial contributors along with projects and actions by other governmental agencies and private developments. Finally, ecosystem restoration planning and implementation of a project can be accomplished when the entire existing degradation is a result of actions by others.

A.7.4 Findings on Mitigation Policies

The Digest of Water Resources Policies and Authorities (EP 1165-2-1) includes information on mitigation requirements for new projects resulting from the discharge of dredged or fill material as addressed under the auspices of the Clean Water Act, and new project reports prepared under the auspices of Section 906 of WRDA 1986 and the FWCA. Further, mitigation requirements resulting from jeopardy and adverse modification opinions under the Endangered Species Act are reflected in the development of reasonable and prudent measures. Regarding existing projects and mitigation for previous effects of experienced negative impacts, Section 216 of the River and Harbor and Flood Control Act of 1970 can be used to study the situation and identify possible measures. However, expenditures under this authority are limited to $20,000 per study. Therefore, Section 216

is used as a reconnaissance type study that leads to a cost-shared feasibility study, and eventually to a cost-shared project.

Mitigation measures, per se, for both new and existing projects must be environmentally justified based on the potential loss of significant fish and wildlife resources, and economically justified by the consideration of the cost effectiveness of various mitigation alternatives. A key issue to note is the need for careful planning and evaluation of a variety of mitigation measures, both singly and in combination, in the development of a justified mitigation project. Further, due to the requirements of the FWCA, the policies and recommendations of the USFWS are important relative to mitigation planning that address both previous and future effects. Coordination by the Corps with the USFWS and the NMFS, as appropriate, is a central feature of the requirements of the FWCA.

Based upon the laws and related Corps policies summarized herein, along with the mitigation policies and guidance of the USFWS in relation to the requirements of the FWCA, the following conclusions regarding mitigation policies are articulated:

- Requirements related to the planning and development of mitigation for future effects features for new water resources projects are found in several laws, including NEPA, the Clean Water Act, WRDA 1986, the Endangered Species Act, and the FWCA. The authority of Section 216 of the River and Harbor and Flood Control Act of 1970 can be used to perform an initial examination of experienced negative impacts of existing water resources projects, and may lead to further study and implementation of cost-shared mitigation for previous effects projects, as appropriate.

- Mitigation measures that address both previous and future effects must be justified based upon the actual or potential loss of significant fish and wildlife resources, and the application of a developed procedure for incremental cost analysis that includes metrics for environmental benefits along with costs for various mitigation features.

- Familiarity with the mitigation policies and typical recommendations for mitigation measures and means used by the USFWS can facilitate the required coordination between the Corps and USFWS under the auspices of the FWCA.

A.7.5 Findings on Policies on Water Quality and Streambank Erosion

ER 1110-2-8154 addresses water quality and environmental management for Corps projects. As such, it is a uniquely important Corps regulation related to mitigation of both previous and future effects. The national policy of the Federal government regarding water quality management is articulated along with the Corps' companion policy, specific commitments, and three management objectives. Regarding mitigation for previous effects, ER 1110-2-8154 indicates that the Corps can address situations where degraded conditions regarding water quality and/or aquatic or riparian habitats are a result of Corps actions alone, and/or combinations of actions by other governmental agencies and the private sector. Further, Chapter 18 of EP 1165-2-1 (Digest of Water Resources Policies and Authorities) stresses the importance of water quality standards in water quality management planning and the development of mitigation projects. The standards can be

used as one basis for determining the significance of degraded conditions and anticipated impacts from new water resources projects.

Corps policies regarding mitigation for previous effects projects for streambank erosion are included in the Planning Guidance Notebook (ER 1105-2-100), Chapter 15 in the Digest of Water Resources Policies and Authorities (ER 1165-2-1), Section 14 of the Flood Control Act of 1946, Section 103(a) of WRDA 1986, and Section 202(a) of WRDA 1996. These policies are primarily focused on remediating erosion problems threatening public facilities and certain non-profit public services.

Based upon this information, the following key conclusions are drawn:

- ER 1110-2-8154 (Water Quality and Environmental Management for Corps Civil Works Projects) is a uniquely important regulation that addresses all mitigation. This ER includes information that directly or indirectly relates to the Corps' EOPs, including the incorporation of ES and the consideration of cumulative effects in water resources planning.

- Water quality management is intricately linked to the promotion of sustainable conditions for aquatic and riparian habitats and associated species. Further, compliance with water quality standards can be used as an indicator of ES for these habitats and associated species.

A.7.6 Overall Conclusions

The overall conclusions of this study are as follows:

- The issuance of seven EOPs in March, 2002, EC 1105-2-404 in May, 2003, and ER 200-1-5 in October, 2003, has provided the foundation and institutional basis for the incorporation of ES in the Corps' development of water resources plans, programs, and projects. In addition, mitigation addressing both previous and future effects is inferred in the EOPs and the EC. Further, CEA requires the consideration of mitigation measures for past, present, and future cumulative effects; thus, planning, coordination, and implementation of both types of measures may be necessary in order to enhance the ES of significant resources.

- The Corps can utilize several statutory authorities for the planning, coordination, and implementation of mitigation measures addressing both previous and future effects for continuing and new projects and their operation. These authorities are contained in selected sections of four WRDAs (Sections 904, 906, 907, 940, and 1135 of WRDA 1986, Sections 306 and 307 of WRDA 1990, Sections 204 and 205 of WRDA 1992, and Sections 206 and 207 of WRDA 1996); and in Section 216 of the RHFCA of 1970. Further, the FWCA of 1958 encompasses mitigation for both previous and future impacts on fish and wildlife resources, and it requires active coordination between the Corps and the USFWS and/or NMFS regarding mitigation. A key point in application of these authorities is that costs must be shared with a non-federal sponsor in order to implement, and in many cases, to study mitigation measure for either previous or future effects.

- The terminology found in various Corps policies, regulations, and guidance is often confusing and overlapping. For example, mitigation can refer to measures addressing the past, present, and/or future. Protection is sometimes subsumed within mitigation or ecosystem restoration, or it may be addressed as a separate measure. Accordingly, careful reading is necessary when searching for Corps policies and practices related to mitigation.

- Ecosystem restoration, which is a current major mission of the Corps, can include measures related to reducing historical degradation of resources (mitigation for previous effects) as well as measures that are protective against future degradation (mitigation for future effects). Three categories of authorities can be used to plan and implement such restoration projects. They include Congressionally authorized studies and provisions in existing laws, programmatic authorities within specific sections of recent WRDAs, and existing operation and maintenance authorities for specific projects. Ecosystem restoration projects can be developed where previous Corps projects or actions are the sole contributor to degraded resources, or where they are partial contributors along with projects and actions by others. Further, in certain circumstances, such projects can be accomplished when the entire degradation is a result of actions by others.

- Requirements related to the planning and development of mitigation features for new water resources projects are found in several laws, including NEPA, the Clean Water Act, WRDA 1986, the Endangered Species Act, and the FWCA. Further, mitigation measures for future effects, as well as measures for previous effects, must be justified based upon the actual or potential loss of significant fish and wildlife resources, and the application of a developed procedure for incremental cost analysis that includes metrics for environmental benefits along with costs for various mitigation features.

ER 1110-2-8154 (Water Quality and Environmental Management for Corps Civil Works Projects) is a uniquely important regulation that addresses mitigation for both previous and future effects. This ER is important because water quality management is intricately linked to the promotion of sustainable conditions for aquatic and riparian habitats and associated species. Finally, policies and practices related to mitigation for previous effects projects for streambank erosion are delineated in the Planning Guidance Notebook (ER 1105-2-100) and the Digest of Water Resources Policies and Authorities (EP 1165-2-1).

- It is important to note that, while there are numerous authorities for study and implementation of mitigation for previous effects (or ecosystem restoration), costs must be shared with a non-federal sponsor in order to implement, and in many cases, to study either mitigation measures.

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_____, "Regulatory Guidance Letter 01-1, Guidance for the Establishment and Maintenance of Compensatory Mitigation Projects Under the Corps Regulatory Program Pursuant to Section 404 (a) of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899", October 31, 2001, Washington, D.C.
_____, "RFFA Matrices for a Navigation System Programmatic Impact Study", May 30, 2003, Pittsburgh District, Pittsburgh, Pennsylvania.
_____,"USACE Environmental Operating Principles and Implementation Guidance", March 26, 2002a, Washington, D.C.
_____, Environmental Quality - Policy for Implementation and Integrated Application of the U.S. Army Corps of Engineers (USACE) Environmental Operating Principles (EOP) and Doctrine. ER 200-1-5, October 30, 2002, Washington, D.C.

_____, "Water Quality and Environmental Management for Corps Civil Works Projects", ER 1110-2-8154, May 31, 1995, Washington, D.C., pp. 2-4, and 8.

Exhibit B

SCOPING

B.1 SUMMARY OF U.S. ARMY CORPS OF ENGINEERS PUBLIC SCOPING PROCESS

B.2 ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

SUMMARY OF U.S. ARMY CORPS OF ENGINEERS' PUBLIC SCOPING PROCESS OHIO RIVER MAINSTEM SYSTEM STUDY (ORMSS)

These materials summarize comments received during the scoping process for the Cumulative Effects Assessment (CEA) of the USACE Ohio River Main Stem System Study (ORMSS) during Summer 2001. An important first step in developing a large-scale environmental impact statement, scoping is mandated by the National Environmental Policy Act whenever major federal actions can significantly affect the quality of the environment. Scoping creates opportunities for the public, agencies and other groups to provide input on potential issues related to a proposed project. By identifying significant environmental issues and potential alternatives, the scoping process will influence development of the CEA.

SUMMARY OF ORMSS SCOPING PROCESS

Scoping for the CEA began with publication of a notice in the Federal Register on June 26, 2001. It also was publicized through a press release announcing the CEA scoping process and inviting comments, a mailing to all addressees on the ORMSS mailing list, and legal ads in major regional newspapers. Interested parties also were encouraged to provide written comments or submit questions to the CEA Project Manager at USACE Louisville District by regular mail or e-mail (celrl-ormss@usace.army.mil) by August 31, 2001. Information about the CEA also was available on the project web site: http://www.lrl.usace.army.mil/ormss/. Additionally, a color brochure was developed and provided to those who attended the public meetings and to others upon request.

A series of six public scoping meetings (one set in each state along the Ohio River) was held during Summer 2001. Each set consisted of a daytime meeting with governmental agencies and an evening meeting open to the public. Meetings were scheduled as follows:

July 10, 2001 - Banterra Bank, Metropolis, IL
July 12, 2001 - Victory Theater, Evansville, IN
July 31, 2001 - Mid-Ohio Valley Regional Council , Parkersburg, WV
August 1, 2001 - Community College of Beaver Co., Monaca, PA
August 6, 2001 - Kenton Co. Public Library, Covington, KY
August 7, 2001 - Shawnee State University, Portsmouth, OH

Forty-four people attended the six meetings with agency representatives. More than half the participants represented federal and state resource or regulatory agencies. The remaining participants represented various public agencies or business interests.

A total of 141 people signed in at the six public meetings. Nearly 50 percent of the participants were interested citizens. Approximately 25 percent represented business or development interests, with the largest representation from the shipping industry. The remaining participants included fishermen, elected officials, and representatives of environmental groups, the media and government agencies.

Questionnaires also were available at the meetings and online. Nineteen completed questionnaires were submitted. Additionally, written comments received during scoping consisted of several personal and agency letters and e-mail messages. By late summer, 24 written responses had been received.

ISSUES IDENTIFIED DURING SCOPING

The accompanying table summarizes issues that emerged during scoping and indicates the number of related comments. A more detailed summary of the USACE's scoping process will be part of the Cumulative Effects Assessment when it is completed.

ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

Comment	No.*	Action
OHIO RIVER MAINSTEM SYSTEMS STUDY (ORMSS)		
1) Study may overemphasize transportation and river commerce	1	Comment noted
2) Sufficiency of input from other federal agencies	1	Currently being addressed
3) Issuance of an official Record of Decision (ROD) for ORMSS	1	Will occur
4) Application of Ohio River Navigation Investment Model to ORMSS	1	Will occur
5) Relationship between ORMSS and completion of Olmstead L/D	1	Will be addressed
6) Integration of ORMSS with the U.S DOT Marine Transportation Study	1	Will be addressed
7) Sufficiency of public meeting notification process	4	Comment noted - Notification procedures being revised
8) Procedures for obtaining additional ORMSS information	1	Addressed in meetings
9) Date public scoping period ends	2	Addressed in meetings
10) How to get on mailing list for future meetings or follow-up information	2	Addressed in meetings
11) Use of Waterways Journal to communicate ORMSS information	1	Currently being addressed
12) Use of AWO and DINAMO to notify towing industry of public meetings	1	Currently being addressed
13) Interest in including major tributaries in project scope	3	Comment noted
14) How ORMSS study will affect Greenup L/D upgrade	1	Addressed in meeting
15) Need for ORMSS to address liveability issues of 2-for-3 (EMD) plan	1	Comment noted.
16) Inclusion of no-action alternative in ORMSS	1	Will be addressed
17) Effect an individual can have on ORMSS process	1	Addressed in meeting
18) Need for ongoing coordination & cooperation with concerned agencies &groups	3	Currently being addressed
19) USACE misrepresented intent of scoping meetings and should re-hold them	1	Comment noted - No Further Meetings Planned
CUMULATIVE EFFECTS ASSESSMENT (CEA)		
1) Tendency for CEAs to emphasize negative impacts	1	Comment noted
2) Need for CEA to consider more than navigation structures	3	Will be addressed
3) Need to learn from other CEAs	1	Currently being addressed
4) Interest in including a vision for the river in the year 2060	1	Will be addressed
5) Methods to be used for assessing water quality	2	Currently being addressed
6) Clarification of relationship between CEA and site-specific impacts	2	Addressed in meeting
7) Accuracy of models for predicting population growth & development	2	Will be addressed
8) Relationship between CEA findings and USACE actions	3	Will be addressed
9) Development of ongoing program to reevaluate cumulative effects every 5 years	1	Comment noted
10) How CEA is weighed against cost effectiveness of a project	1	Comment noted
11) Relationship between CEA and SIP product schedules	1	Comment noted
13) Importance of including commercial dredging & associated permitting process in CEA	2	Will be addressed
14) Need to adhere to Council on Environmental Quality's 1997 guidelines for CEAs	1	Currently being addressed
15) Need to consider 404 application approvals and resultant actions as direct USACE actions	1	Comment noted
16) Need to consider most operations of commercial navigation system as direct USACE actions	1	Comment noted
17) Use CEA as a guide in assessing the propriety of USACE projects	1	Comment noted
18) Interest in receiving an executive summary of the CEA	1	Comment noted
19) Interest in documenting CEA process and using the OR CEA as a model for other efforts	1	Comment noted

ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

Comment	No.*	Action
BASELINE CONDITIONS		
1) Need to define, limit and establish parameters of baseline conditions.	10	Currently being addressed
2) Importance of coordination with resources agencies in determining baseline conditions	2	Currently being addressed
3) Need to define parameters for Reasonably Foreseeable Future Actions (RFFAs)	3	Currently being addressed
4) Importance of understanding baselines for different environmental components	2	Currently being addressed
5) Will aquatic studies be performed for baseline condition or construction	1	Addressed in meeting
BARGE OPERATIONS		
1) Loss of shoreline trees and river property caused by barge activity	7	Will be addressed
2) Reliability of barge traffic forecasts	5	Will be addressed
3) Failure of barges to stay in designated shipping lanes	2	Comment noted
4) Increased spills and accidents potentially affecting aquatic life and impairing water quality.	1	Will be addressed
5) Changes in shipping demand as low sulfur coal reserves near depletion in next 25 years	2	Comment noted
6) Possible trash hauling by barges in the future	2	Comment noted
7) Difficulty in gaining access to Monroe Co., OH park property at Sunfish Creek near L/D 14 due to barge loading	1	Will be used & addressed under recreation
8) Why USACE expects only 1% increase in barge traffic, while a 3% increase in gross domestic product is expected	1	Addressed in meeting
9) Barges shine lights into residences.	2	Comment noted
10) OH Division of Watercraft receives many complaints about barges damaging shoreline near Greenup L/D	1	Will be addressed
11) Safety concerns related to uneven arrangement of barges on towboats	1	Comment noted
NAVIGATION INFRASTRUCTURE		
1) Navigation structures presently not keeping pace with traffic demands	3	Will be addressed
2) ORMSS schedule possibly lagging behind future navigation needs	5	Will be addressed
3) Clarification of scheduling and frequency of lock closures	1	Addressed in meeting
4) Eligibility of locks for classification as historic structures	1	Addressed in meeting
5) Possible issuance of bonds to fund navigation improvements	1	Addressed in meeting
6) View of navigation improvements as benefiting only shipping industry	1	Comment noted
7) Status of funding for John T. Myers L/D project	1	Comment noted
8) Assessment and documentation of Olmstead construction	1	Addressed in meeting
9) Why economic forecast model is based on use of auxiliary locks	1	Addressed in meeting
10) Has ORNIM (navigation investment model) been run on the system	1	Addressed in meeting
11) Status of Dashields L/D	1	Addressed in meeting
12) What are current cost estimates onlock extensions at John T. Myers and Greenup L/Ds	1	Addressed in meeting
13) Effects of Greenup L/D/ improvements on barge queueing	1	Addressed in meeting - will be included in CEA
14) What is priority of vessels at locks	1	Addressed in meeting
15) Support expressed for value & maintenance of OR navigation system	3	Comments noted.

ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

Comment	No.*	Action
WATER QUALITY		
1) Cumulative effect of discharges to river may offset water quality improvements.	4	Will be addressed
2) Challenge to water quality presented by CSOs and SSOs	2	Will be addressed
3) High levels of mercury, arsenic, fecal coliform bacteria and agri-chemicals in surface water	1	Will be addressed
4) Need for more stringent discharge permitting procedures or moratorium on permits	2	Comment noted
5) Importance of coordination between USACE and OR public water suppliers	1	Will be addressed
6) Prolonged bureaucratic procedures in obtaining discharge permits	1	Comment noted
7) Possibility of implementing mechanical aeration in mainstem pools	1	Comment noted
8) Importance of continued water quality improvements as a high priority	1	Will be addressed
GROUNDWATER		
1) Overall effects of navigation structures and activities on groundwater levels	1	Will be addressed
2) Need to protect public groundwater supplies.	1	Will be addressed
SEDIMENTATION		
1) Mouths of tributaries silted in, impairing fish habitat, limiting access and damaging property	5	Will be addressed
2) In-stream sedimentation forming bars and causing vessel groundings	1	Will be addressed
3) Need to improve sediment and erosion control from public and private developments	1	Comment noted
4) Need for long-term plan to address silt removal and prevent future sedimentation	1	Comment noted
DREDGING		
1) Damage/destruction of mussel beds and fish spawning areas	4	Will be addressed
2) Possible use of dredge spoils to improve riparian or island habitat or for upland filling	2	Will be addressed
3) Impaired water quality & bioaccumulation in fish tissue of harmful substances stirred up by dredging	2	Will be addressed
4) Importance of maintaining shipping channel	2	Will be addressed
5) Potential partnering with private enterprise to remove marketable aggregates when dredging	1	Comment noted
6) Number of comments that were voiced about in-channel disposal	1	Comment noted
7) Habitat damage caused by Corps permitted commercial sand and gravel dredging		
BANK/SHORELINE INSTABILITY		
1) Bank undercutting & failure caused by increased barge traffic & queuing and wave action	7	Will be addressed
2) Bank erosion caused by USACE-controlled pool fluctuations	3	Will be addressed
3) Shoreline instability threatening costly restoration projects in wildlife management areas	1	Will be addressed
4) Severe erosion occurring at Slough Wildlife Mgmt. Area (downstr. from Henderson, KY)	1	Comment noted

ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

Comment	No.*	Action
POOL ELEVATIONS		
1) Potential adverse effects of higher elevations on bridges, other infrastructure and property	6	Will be addressed
2) Pools maintained at higher level than agreed on in flowage easement contracts with property owners	2	Comment noted
3) Need for elevation management to prevent water levels from exceeding flood stage	1	Comment noted
4) Effects on recreation and quality of life of raising Montgomery pool level	1	Comment noted
5) Coordination of TVA and USACE on management of pool elevations below Tennessee River	1	Comment noted
6) Economic impacts if pool elevations change	1	Comment noted
7) Potential effects on siting of proposed Beaver County Industrial Museum	1	Comment noted
LAND USE		
1) Loss of significant farmland to urban development along river corridor	3	Will be addressed
2) Loss of green space & wildlife habitat with development of marina facilities	5	Will be addressed
3) Development of floodplains & wetlands resulting in increased runoff and habitat loss	4	Will be addressed
4) Need to develop comprehensive plans for development along river	3	Will be addressed
5) Need for coordination with community floodplain coordinators along river	1	Will be addressed
RECREATION/FISHING		
1) Need more public access ramps in each pool to reduce recreational crafts' usage of locks	5	Will be addressed
2) Degradation of recreational value of river caused by increased industrialization	2	Will be addressed
3) Health and safety concerns related to increased traffic and development	3	Will be addressed
4) Effects on fishing caused by water level fluctuations	3	Will be addressed
5) Underrepresenting of fishermen in ORMSS scoping process	1	Comment noted
6) Interest by Ohio to promote Ohio River as a vacation destination	2	Will be used under recreation
7) Increase in barge loading/unloading facilities limiting fishing access from shore	1	Will be addressed
8) Danger to recreational users of submerged trees toppled by bank erosion	1	Will be used under recreation
9) Need for examination of those licensed to operate recreational craft	1	Comment noted
10) Suggestion of greater use of levees for passive recreation	1	Comment noted
11) Increased development of scenic byways and bikeways	2	Comment noted
12) Effects on recreation and heritage sites in Illinois, including Tower Rock Recreation Area	1	Will be used & addressed under recreation
13) Include recreational facilities as design components of L/D revitalization & construction projects	1	Comment noted
14) Need for long-term plan for replacement & maintenance of existing recreational launch ramps	1	Will be addressed
15) Need more access ramps in each pool for emergency response and boating safety officials	1	Will be addressed
FISH & WILDLIFE		
1) Need for fish habitat improvements, including fish passages around locks and dams	2	Will be addressed
2) USACE role when fish kills occur	1	Comment noted
3) Loss of wildlife corridors as shoreline develops	2	Will be addressed under land use
4) Stress and disruption of waterfowl migratory patterns caused by barge traffic	1	Will be addressed under aquatic resources
5) Loss of unique, sensitive species due to water quality problems and habitat modifications	2	Will be addressed.

ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

Comment	No.*	Action
THREATENED & ENDANGERED SPECIES		
1) Need for USACE to coordinate with U.S. Fish and Wildlife Service on these issues	1	Currently being addressed
2) Potential displacement of interior least tern from Cottonwood Island	1	Comment noted.
3) Riverfront development constraints related to endangered species	1	Comment noted
4) Effects related to 3 crayfish species, 2 fish species and 7 freshwater mussel species in IL	2	Will be addressed
EXOTIC/INVASIVE SPECIES		
Need to prevent distribution of exotic /invasive plants and animals through USACE actions	1	Will be addressed
OHIO RIVER ISLANDS		
1) Many islands posted for day use only	2	Comment noted
2) Concern that landowners must sell at USACE's price for OR islands Nation Wildlife refuge	2	Addressed in meeting - not a USACE project
3) Potential instability of OR islands & futility of creating islands wildlife refuge	2	Will be addressed
CULTURAL RESOURCES		
1) Need to address the Native American Grave protection and Repatriation Act (NAGPRA)	2	Will be addressed
2) Need to contact state historic preservation offices when specific projects are proposed	1	Comment noted
TRASH		
1) Trash increasingly becoming a problem for property owners and river users	6	Comment noted
2) Need for stricter litter laws	1	Comment noted
3) Role of USACE related to litter and debris in river, especially at locks and dams	3	Will be addressed
AESTHETICS		
Impairment of scenic value of river corridor for millions of people living in the Ohio Valley	1	Will be addressed under aesthetics
PRIVATE PROPERTY		
1) Procurement and control of land by the federal government	3	Comment noted
2) Restrictions placed on property owners participating in federal programs	2	Comment noted
ENERGY		
Possibility of developing hydroelectric power at dams	5	Comment noted
ENVIRONMENTAL REGULATIONS		
1) Need to increase funding for & improve enforcement of current regulations & develop new ones	2	Comment noted
2) Estimated number of officers that enforce shipping regulations along OR	1	Comment noted
3) Centralize enforcement efforts	1	Comment noted

ORMSS PUBLIC SCOPING ISSUES AND PLANNED ACTIONS

Comment	No.*	Action
INTERMODAL TRANSPORTATION FACILITIES		
1) Enhancement of river transportation capabilities through corresponding development/improvement of intermodal transportation facilities	2	Will be addressed
2) Need for long-range coordination with FHWA , state & local transportation agencies	1	Currently being addressed
3) Need to integrate navigation with other transportation modes	2	Will be addressed
ECOSYSTEM RESTORATION PROGRAM (ERP)		
1) How, when and where the ERP will be funded and implemented	7	Addressed in meeting
2) Clarification of relationship between ORMSS and ERP	6	Addressed in meeting
3) Understanding of what constitutes ecosystem restoration	2	Addressed in meeting
4) Potential difficulty in finding non-federal partners	2	Comment noted
5) Ability of partners to raise 35% local match for ecosystem restoration projects	2	Comment noted
6) Inconsistency of ERP with USACE's main objectives	1	Comment noted
7) Potential application of eminent domain in the ERP	1	Comment noted
8) Need for eminent domain in restoration of Ingram Island	1	Comment will be forwarded to ERP team
9) Clarification of relationship between ERP and treatment of municipal stormwater	1	Comment noted
10) Reason only certain construction activities are included in the ERP	1	Comment noted
11) ERP seems to favor projects outside Illinois.	1	Comment will be forwarded to ERP team
12) Will strategic planning for ERP occur	1	Comment will be forwarded to ERP team
13) Need to focus on riparian corridors & green space near power plants	1	Comment will be forwarded to ERP team
14) Importance of considering ERP in the ORMSS "future without project "condition	1	Comment noted
OTHER QUESTIONS/CONCERNS		
1) Clarification of difference between floodway and floodplain	1	LRL owes a response
2) Occurrence of site-specific mitigation for site-specific projects	1	Comment noted
3) Need for USACE to encourage uniformity in navigation charts along length of OR	1	Comment noted
4)Consideration by USACE of side-aside amount and other enhancements separate from mitigation	1	Comment noted
5) Will USACE do site-specific environmental documents for each action	1	Addressed in meeting
6) What about ancillary movement of goods and services in emergencies e.g. bridge destruction	1	Will be addressed
7) Will USACE suggest different BMPs related to certain activities e.g. clamshell unloading	1	Comment noted
8) Effects on 4 Wild & Scenic Rivers proposed for Illinois	1	Will be addressed
9) Importance of continued air quality improvements as a high priority	1	Comment noted
10) Need for adequate financial resources to complete the mitigation requirements within the 401 certification program	1	Comment noted

* Denotes total number of times comment was made during the scoping process.

Appendix C
LAND USE

C.1 TABLE OF CONTENTS

Definition of River-Related Land Use

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Past to Current Baseline Conditions

Cumulative Effects: Past to Current and Foreseeable Future Actions

Assessment of Effects

References

C.2 DEFINITION OF RIVER-RELATED LAND USE

Land uses are related to socioeconomic and ecological resources in the CEA planning context. Consequently, this appendix includes information relevant to several VECs. Land use changes occur as a result of population increases or decreases in localized areas. Economic development and infrastructure projects can also lead to direct changes in land use as well as associated changes in population density. River-related land use applies these concepts to address how human use of the Ohio River has shaped or influenced associated land use patterns and what land use changes may be anticipated in the foreseeable future.

C.3 OBJECTIVES AND SCOPE OF THE LAND USE STUDY

C.3.1 Objectives

This chapter assesses the system-wide cumulative land use impacts of all likely major navigation improvements along the mainstem of the Ohio River from 2000 - 2060. Land use impacts that are directly or indirectly attributable to modernization of the navigation system are evaluated in concert with impacts from other past, present and reasonably foreseeable future actions (RFFA) by the US Army Corps of Engineers (Corps) and others.

Assessment of past and present actions and current conditions is the basis for identifying and interpreting the potential impacts of RFFA. These future actions include the major navigation improvements identified in this study, other routine or potential actions by the Corps, projected actions by other federal, state, or local agencies, and predictions of general economic expansion and development.

The results of the cumulative effects assessment are intended to contribute to two topics of subsequent public debate; whether the impacts of the RFFAs constitute acceptable outcomes for the affected resources and how the proposed navigation improvements contribute to those outcomes.

C.3.2 Geographic Scope

The geographic focus for land use impacts includes those regions most directly impacted by operation and maintenance of the navigation system. This includes lands along either bank of the Ohio River lying "between the bluffs." This "floodplain zone" is defined as the meander channel of the Ohio River and includes the 100 and 500 year floodplains as well as terraces of level land lying above these flood zones. Land use patterns are also discussed in the context of larger adjacent regions (e.g. counties adjacent to the main stem of the Ohio River or multi-county metropolitan areas). Statewide land use patterns are discussed for purposes of comparing the Ohio Valley area to regional patterns and trends.

C.3.3 Time Frame

The established time frame for this project is 1920 to 2060. The earlier date approximates the initiation of Corps lock and dam construction activities on the Ohio River. The latter date approximates the end of the 60-year planning horizon encompassed by the Ohio River Main Stem Study (ORMSS).

Discussion of land use patterns requires consideration of settlement and development patterns prior to 1920. Understanding some of the general factors that contributed to the land use patterns (and ongoing trends) along the Ohio River in 1920 will be important to

discussion of how the lock and dam construction activities contributed to subsequent changes in land use patterns.

C.4 ISSUES FROM SCOPING

A series of 12 public scoping meetings was held during Summer 2001 in communities along the Ohio River. The meetings created opportunities for the public, state and local agency representatives, and other interested groups to provide input on potential issues related to the CEA. Meeting attendees could provide input through comments during the question and answer sessions, completion of questionnaires, or direct written comments. Direct mailings and advertisements of the meetings also provided opportunities for public comments via questionnaires, letters, or email. A more detailed discussion of the scoping meetings is presented in Chapter 2 – Procedure and Special Methods.

185 people attended the meetings and over 200 verbal comments were recorded from the question and answer sessions. These comments accounted for the large majority of input. Additional comments were obtained from 19 questionnaires and several letters that were submitted. Comments that directly or indirectly addressed land use issues are presented in **Table C-1**.

TABLE C-1
Comments from Public Scoping Meetings

Direct Land Use Comments	Total
Loss of green space & wildlife habitat with development of commercial and recreational docking/loading facilities	5
Development of floodplains & wetlands resulting in increased runoff and habitat loss	4
Loss of significant farmland to urban development along river corridor	3
Need to develop comprehensive plans for development along river	3
Need for coordination with community floodplain coordinators along river	1
Other Comments with Land Use Implications	
Loss of shoreline trees and river property caused by barge activity	8
Bank undercutting & failure caused by increased barge traffic, queuing and wave action	7
Potential adverse effects of higher pool elevations on bridges, other infrastructure and property	6
Bank erosion caused by USACE-controlled pool fluctuations	3
Possible use of dredge spoils to improve riparian or island habitat or for upland filling	2
Shoreline instability threatening costly restoration projects in wildlife management areas	2
Loss of wildlife corridors as shoreline develops	2

C.5 INDICATORS OF ENVIRONMENTAL SUSTAINABILITY

Land use patterns in this chapter are discussed primarily with reference to use definitions and measurements of the Natural Resources Conservation Service (NRCS) National Resources Inventory (NRI). The NRI is conducted every five years (most recently in 1997) and measures actual use of nonfederal lands. Use categories include cropland (row crops such as corn, soybeans or wheat), pastureland (grazing and hay production), forest land, developed land, and other (primarily federal land plus open water). The category for developed land is intended to identify lands that have been

permanently removed from the rural land base and includes: large tracts of urban and built-up land, small tracts (<10 acres) of built-up lands, and land outside of built-up areas that is in roads, railroads and associated rights-of-way (USDA, Dec. 2000). The NRI provides published data at the state level for the years 1982, 1987, 1992, and 1997.

NRI data for 1992 was also utilized in development of the National Land Cover Data Project (NLCD92). This product was prepared by the National Land Cover Characterization project and provides thematic mapping of land use patterns for the coterminous U.S. This multi-agency project (USGS, NRCS, EPA, others) utilized satellite data and supporting information including topography, census, agricultural statistics, soil characteristics, other land cover maps, and wetlands data to determine and label the land cover type at 30 meter resolution. Twenty-one classes of land cover were mapped, utilizing a modified Anderson level II classification (Vogelmann, 2001).

Indicators of environmental sustainability, which vary by VEC, generally provide benchmarks for measuring cumulative effects on a given resource or VEC. In the context of this study, the principal environmental sustainability indicators would appear to be developed land and the rate at which other land uses are converted to developed land.

C.6 LAWS, REGULATIONS, ORDINANCES AND PROGRAMS

Land use patterns in the U.S. are primarily unregulated or locally regulated, no federal or state laws directly control how privately owned land is used within the six states of the Ohio Valley. A limited set of federal and state resource protection regulations (wetlands mitigation, dredge and fill permits, protection of cultural features) may provide some indirect influence on land use decisions, but these regulations do not specifically prohibit any proposed development. Land use planning and zoning is traditionally the responsibility of local municipalities, supplemented by the coordinating role of regional planning authorities in some locations.

Most planning authorities treat agricultural uses within their jurisdiction as unregulated and focus on the management (or promotion) of development activities. Planning authorities typically seek to achieve identified outcomes by establishing zones for specified activities and providing (or withholding) infrastructure related to the desired activity. Competing actions of individual municipalities can be counterproductive and regional authorities are intended to balance development so that all participants may benefit. The regional approach often focuses on development of regional transportation infrastructure and larger scale industrial zones to keep or attract desired business activities. However, economic growth or decline in any area is dependent on a large and complex set of factors and planning authorities are likely to operate in a primarily reactive mode when economic change proceeds contrary to predicted or desired outcomes.

C.7 PAST TO CURRENT BASELINE CONDITIONS

C.7.1. Settlement and Development Patterns Prior to 1920

Pioneer settlement within the Ohio River valley prior to the 1790's was constrained by French and British interests in maintaining their claims of sovereignty within the region. While these efforts did prevent or postpone early colonization efforts, American interests were well aware of resource opportunities in the region as the cumulative result of

military and peacetime surveying expeditions dating from the French and Indian Wars of 1754 (USACE$_c$ pg. 3-4). Pressure to colonize the area was furthered by the awarding of lands in the Northwest Territories to veterans of the American Revolution. However, Native American resistance (often supported by British influences) continued to minimize colonial settlements in the area. It was not until Anthony Wayne's victory at the Battle of Fallen Timbers in northwestern Ohio in 1794 and the conclusion of the Treaty of Greeneville in 1795 that the threat of Indian attacks on Upper Ohio River settlements was eliminated and the development of towns and communities in the river valley could proceed unimpeded (USACE$_c$ pg. 3-8). The population within the Ohio Valley grew from 125,000 in 1790 (the first Federal Census) to 850,000 in 1810 (USACE$_c$ 3-55).

The decades of pre-settlement military activity necessitated the establishment of several fortifications along the Ohio River or its tributaries and these often became the sites of the earliest settlements within the region. The most notable example is Pittsburgh, located at Fort Pitt (circa 1758), other examples include fortifications preceding the establishment of towns at Marietta, OH and Wheeling and Point Pleasant, WV (USACE$_c$ 3-8). Other factors contributing to the initial location of towns along the Ohio River generally included the availability of high ground for a town site above the flood zone, connectivity between the town and a productive hinterland, and certain 'port development opportunities' such as the Falls of the Ohio at Louisville or location of the national road crossing at Wheeling. Initial settlements within the region tended to cluster along the Ohio River because the river was the primary access to the region.

A variety of factors influenced the subsequent growth and decline of Ohio River towns from 1830's to 1920's. Some early riverfront settlements subsequently prospered as hubs or service centers to interior regions accessed through these towns. As the hinterlands developed, the river towns continued to grow as ports for the assembly and shipping of the region's produce. During the early decades of this period, the Ohio River provided the primary mode of transportation, both for immigration of new settlers and for transport of regional products. The earliest flatboats and keelboats mostly provided one-way transport downstream, necessitating shipment of produce through New Orleans and coastal shipping to reach eastern markets. The arrival of steamboats around 1815 permitted two-way traffic and greatly reduced travel times (USACE$_c$ 3-60). However, the Ohio River remained largely unimproved prior to the 1920's and the ability to move produce was constrained by the seasonal availability of high water flows sufficient to support navigation. Development of the Ohio River in the 1800's included the removal of snags, completion of the initial canal and locks around the Falls of the Ohio at Louisville in 1833, and completion of the first wicket dam (Davis Island, Pittsburgh) in 1885.

Inland canals provided the first significant alternative or supplement to river transport, beginning in 1825 with completion of the Erie Canal from Buffalo to New York City. Important canals in the Ohio River Valley included the Ohio & Erie which connected Lake Erie to Portsmouth, OH; the Pennsylvania Mainline from Pittsburgh to Philadelphia; and the Pennsylvania & Ohio, connecting Pittsburgh to the Mahoning River Valley in Ohio (USACE$_c$ 3-21). By 1830, approximately 3,000 miles of canal operated in the United States. Canals provided nearly year-round transportation and the ability to ship products more directly to eastern markets instead of overland from Upper Ohio, Allegheny, or Monongahela ports. On balance, canal development probably supplemented river traffic more than it competed with or replaced river traffic; steamboats hauled goods to canal terminals on the Ohio River, creating an early form of multi-modal ports.

Railroads provided a far more significant level of competition to river transport and quickly became the primary means of commercial transportation in the region. They provided true year-round transport capabilities, greatly reduced transport times, and could be quickly built to serve any point-to-point opportunity. The first railroad in the Middle Ohio River Valley was completed in the 1840's, connecting Lake Erie with the Ohio River. By 1850, 242 miles of track were completed in the Middle Ohio River Valley. By 1855, this number exploded to 1247 miles, and virtually saturated rail transport opportunities in the region. Rail mileage in the region grew only an additional 80 miles by 1860 ($USACE_c$ 3-25). Railroads almost immediately rendered canals obsolete, sometimes laying track beside or over the abandoned canals.

Commercial river transport also declined at a slow but steady pace in competition with railroads. The year-round operability of rails had a distinct advantage over the seasonal limitation of steamboats. Inland cities with good rail connections grew substantially. To a large degree, the early river port towns along the Ohio River either prospered or perished with the railroads, depending on their ability to attract rail service. Subsequently, further prosperity came to most towns able to establish railroad bridges across the Ohio River.

The latter part of this era includes the period of heavy industrial development along the middle and upper Ohio River. This development centered on the iron and steel industry in Pittsburgh, with its convergence of proximity to raw materials, coal, river water and rail and river transportation to move materials and produce in and out of this center. An almost continuous band of industrial development became established along the Ohio River floodplain from Weirton to Pittsburgh. To compensate for the limited availability of high ground within this corridor, industries built up elevation of the floodplain for their developments. The steel industry typically used large quantities of slag as fill material (Rieger, personal communication).

C.7.2 Settlement and Development Patterns 1920 to Present

Construction of the system of wicket locks and dams ultimately revitalized the Ohio River as a major transportation corridor. Following construction of the first project in 1885 (Davis Island) the next lock and dam was not finished until 1904. Surprisingly, initial construction of the dams was opposed by some members of the barge industry, who feared that breaking up multiple barge tows for passage through the locks would make river freight impractical ($USACE_c$: 1-18). However, completion of the initial projects proved the advantages of this navigation development. Six lock and dam projects were completed between 1904 and 1910, 23 were completed between 1911 and 1920, and the entire system of 50 lock and dam projects was completed by 1929. The original design for a navigation depth of six feet was modified in 1910 to provide for a nine-foot depth.

Sentiment of rivermen began to change to favor canalization after the Davis Island Lock was in operation. During an unexpected flood in July 1888, one hundred coal barges sank along the Ohio River, but no barge in the harbor behind Davis Island was lost. Industry located along the Davis Island pool benefited from a more reliable water supply. Fears that the pool would be stagnant and a breeding ground for disease proved unfounded. Instead, sewage and other obnoxious effluents which had formerly rotted along the

shoreline during low water periods were washed away. Both rivermen and industrialists urged the extension of canalization downriver (Johnson 1977:95).

Even as construction of the slackwater system continued, river traffic declined. In 1917, cargo carried on the river reached a low of about 4.6 million tons, a nadir caused largely by the abrupt halt of coal shipments from Pittsburgh to New Orleans. The turning point for the slackwater system was during World War I. Wartime shipping overburdened the country's land transportation system and by 1920, cargo volume on the Ohio River had risen to almost 9.4 million tons, a total that increased further to 10.8 million tons in 1924 (Froggett 1926a), 16 million tons by 1925 (Froggett 1926b), and 22.3 million tons by 1930 (Robinson 1983:28-29; USACE-ORD 1979:22). Where traffic once consisted primarily of coal and steel products moving downstream, new products were being added as the century progressed. Freight soon included petroleum and its products, iron and steel, dry and liquid chemicals, grain, cement, and a variety of other items (Gaum 1970:487), and upstream traffic substantially increased in volume.

Commerce on the river grew steadily through the 1930s and 1940s while development of diesel towboats and larger barges created opportunities for larger scale, more efficient movement of commodities. Designed for about 15 million tons of commerce annually, the old locks and dams handled more than 70 million tons in 1954; in addition, traffic moving upstream on the Ohio had nearly equaled that moving downstream. Plans to improve system efficiency and accommodate the larger tugs and barges called for reducing the number of dams by building high-lift projects with larger capacity locks. The final plan, approved in 1954, envisioned a total of 19 high-lift projects with dual lock chambers and began with the construction of Greenup and New Cumberland L&Ds, although construction of Emsworth, Dashields, Montgomery and Gallipolis L&Ds during the 1930s had already replaced some old locks and wicket dams on the upper river. Implementation of the current phase of lock extensions overlaps completion of the mid-century modernization program. Olmsted, which will complete the 1954 modernization plan, will replace L&D 52 and 53 (Johnson, 1992).

During this era of sustained urban growth, the demands of industrial and commercial development outpaced the availability of land within some of the rapidly growing riverfront urban centers. Within the Huntington and Louisville Districts, a series of levee and floodwall projects were completed during the 1930s and 1940s to secure more land for development as well as to protect existing properties against flooding. Rapidly growing cities also expanded beyond the river floodplain to higher ground, utilizing mass transit (light rail, bus) and automobiles to connect their expanding fringe with the urban riverfront core.

The availability of reliable, inexpensive electric power contributed significantly to the industrial and commercial growth of the Ohio Valley. Construction of the wicket dams contributed to bulk transport of the region's coal and provided stable pool elevations for the construction of coal fired utilities on the Ohio River and its primary tributaries. Over the years, economies of scale have favored development of the very large power plants that are now a part of the riverfront landscape of the Ohio Valley.

C.7.3 Current Land Use Patterns and Trends in the Ohio River Valley

C.7.3.1.Enhanced Satellite Data

The National Land Cover Data 1992 (NLCD92) product was prepared by the National Land Cover Characterization project and provides thematic mapping of land use patterns for the coterminous U.S for the year 1992. The project utilized satellite data and supporting information including topography, census, agricultural statistics, soil characteristics, other land cover maps, and wetlands data to determine and label the land cover type at 30 meter resolution. Twenty-one classes of land cover were mapped, utilizing a modified Anderson level II classification (Vogelmann, 2001). {Note: The growing need for land-cover and other geospatial data within the federal government culminated in reforming the MRLC Consortium again in 2000 (MRLC 2001), with a second generation national land-cover data set to be developed from year 2000 data called National Land Cover Data 2000 (NLCD 2000). This land-cover mapping effort will be developed using a database approach, which provides flexibility in developing a suite of independent data layers that provide more generic flexibility in applying the database to even more relevant applications. Full production development is anticipated to begin in 2002, with completion targeted for 2004.}

The following illustrations were derived from the NLCD92 data source to provide a qualitative overview of land use patterns within the Ohio River floodplain and adjacent lands. **Figures C-1 through C-11**, plus a description of land cover classifications, are provided at the end of this Exhibit.

Pittsburgh, PA to Steubenville, OH; river mile 0 to 62 (see **Figure C-1**, Ohio River at Pittsburgh, PA).
The floodplain is very constricted, with the river at ordinary high water typically accounting for 30 to 60 per cent of total area of the floodplain (defined as approximately level terrain between steeper bluffs). Low and high-density urban uses (commercial, industrial, high-density residential and low-density residential) dominate all the floodplain, including islands in the upper half of the river reach. Deciduous forest dominates bluffs or steep areas adjacent to the river outside urbanized areas, low-density residential or deciduous forest dominates bluffs within the urbanized areas. Eight islands (3 very small) are visible in the imagery (at maximum magnification).

Low and high-density urban uses dominate upland areas in the eastern half of the area (Pittsburgh area) and also in Beaver, PA and East Liverpool, OH. Deciduous forest and pasture are the principal land uses outside of the urbanized areas. Only a few small areas of cropland or mixed forest (mixed deciduous and evergreen forest) are visible.

Steubenville, OH to Parkersburg, WV; river mile 62 to 187 (**Figure C-2**, Ohio River, Wheeling, WV to Steubenville, OH and **Figure C-3**, Ohio River, Parkersburg, WV to New Martinsville, WV).
The floodplain is very constricted. Significant low and high-density urban uses occur along the full length of this reach and are the dominant land use within the floodplain upstream of Moundsville, WV. The floodplain is primarily in row crops or pasture outside of the urbanized areas, with only a few small areas of deciduous forest. Deciduous or

mixed forest dominates bluffs or steep areas adjacent to the river. Nineteen islands (6 very small) are visible in this reach.

Deciduous forest dominates land use in the upland areas, with pasture as the secondary use. A few urban patches are scattered through upland areas upstream of Moundsville but are confined to upland areas adjacent to the river in communities downstream to Parkersburg. Patches of mixed forest occur throughout the uplands. Only a few small areas of row crop use are visible, some mining or transitional surface use is also visible.

Parkersburg, WV to Ironton, OH; river mile 187 to 323 (**Figure C-4**, Ohio River, Huntington to Parkersburg, WV).
The floodplain is very constricted, widening somewhat in the Huntington to Ironton area. The reach between Huntington and Parkersburg is primarily rural, with only a few small urban areas visible at Gallipolis/Point Pleasant, WV, Cheshire, OH, and Pomeroy, WV. Land use in the floodplain in this section is a mixture of pasture and row crop. Urban land uses dominate the floodplain between Huntington and Ironton. Four islands are visible.

Deciduous forests dominate Upland areas, with pasture the secondary land use. Patches of mixed forest and areas of mining or transitional surface use occur throughout the uplands. Only a few small areas of row crop use are visible.

Ironton, OH to Foster, KY; river mile 323 to 439 (**Figure C-5**, Ohio River, Maysville to Ashland, KY).
The floodplain remains wider from the Ironton/Huntington area to west of Portsmouth, OH then gradually returns to the constricted configuration of the upper river. Land use within the floodplain is primarily row crops with some pasture and a few small areas of wooded wetlands (bottomland hardwoods). Slopes or bluff areas adjacent to the river are primarily deciduous. Urban land use within the floodplain is visible at Ironton/Greenup, Portsmouth, and Maysville. Three islands are visible.

Upland areas are predominately deciduous forest in the eastern and central portions of this area, but give way to mixed pasture and row crops in the western third. Significant row crops are also evident in the broad floodplain of the Scioto River above Portsmouth and significant wooded wetlands occur in floodplains of the Little Sandy River southeast of Portsmouth. Areas of mining or transitional use are scattered through the eastern portion of this area.

Foster, KY to Ghent, KY; river mile 439 to 537 (**Figure C-6**, Ohio River at Cincinnati).
The floodplain remains constricted through the eastern portion of this reach, with the river surface typically accounting for 40 to 60 per cent of the floodplain area. Following the confluence with the Great Miami River, the floodplain broadens somewhat, with the river surface typically accounting for 20 to 40 per cent of the floodplain area. Low and high-density urban use dominates the floodplain in the Cincinnati/Covington/Newport area. Urban use is also visible west of Cincinnati at Cleves, Oh and Lawrenceburg and Rising Sun, IN. Land use in the floodplain east of Cincinnati is primarily a mix of row crops and pasture. Row crops dominate land use in the broader floodplain west of Cincinnati, with some pasture and a few small areas of wooded wetlands. One island is visible in this reach.

Urban uses dominate upland areas adjacent to the Cincinnati area and also occur in scattered patches north, east and south of Cincinnati. Non-urban areas throughout the region include a mix of row crop, pasture, and deciduous forest, with significant row crop areas in the Great Miami floodplain and several areas of wooded wetlands in the floodplains of tributary streams in Kentucky.

Ghent, KY to West Point, KY; river mile 537 to 630 (**Figure C-7**, Ohio River at Louisville).
The floodplain returns to the more constricted form, with river surface accounting for 40 to 60 per cent of the floodplain area. Low and high-density urban use dominates the floodplain in the Louisville/Clarksville/Jeffersonville area. Urban use is also visible east of Louisville at Madison, In, Carrolton, KY, and Vevay/Ghent. Floodplain use outside of urban areas includes a mix of row crops, pasture, and some wooded wetlands. Deciduous forest dominates bluff areas adjacent to the river. Six islands are visible in this reach.

Urban uses dominate upland areas surrounding Louisville and are also visible as smaller patches throughout the area. Non-urban areas throughout the region include a mix of row crop, pasture, and deciduous forest use, with significant areas of wooded wetlands in tributary floodplains northeast of Louisville and scattered patches of mixed forest in Indiana. The large commercial/other area north of Louisville is the Indiana Army Ammunition Plant (INAAP).

West Point, KY to Lewisport, KY; river mile 630 to 737 (**Figure C-8**, Ohio River at Fort Knox).
The floodplain gradually widens from east to west through this reach of the river, with river surface accounting for 20 to 40 per cent of floodplain area in the western area. Urban land use within the floodplain is restricted to a few small centers, including Tell City, IN and Brandenburg, KY. Row crops and pasture are the dominant land uses within the floodplain, with a few small areas of wooded wetlands. Deciduous forest is prominent along bluffs adjacent to the river. One small island is visible in this reach.

Upland areas include deciduous forest (dominant in the central area) and mixed row crop and pasture (dominate in the east and west portions of the area). Significant urban use is located in the Fort Knox area and significant wooded wetlands are located in bottomlands of the Salt River on the east side of Fort Knox.

Lewisport, KY to Wabash River, IN; river mile 737 to 848 (**Figure C-9**, Ohio River at Evansville).
The floodplain continues to widen from east to west through this reach of the river, with river surface accounting for 10 to 20 per cent of floodplain area near the Wabash River confluence. Limited urban land use occurs in floodplain areas of Evansville, IN and Henderson and Owensboro, KY but the majority of urban area for these cities is located on adjacent uplands. Extensive areas of row crop agriculture dominate floodplain land use, with significant secondary areas of wooded wetlands and some pasture and deciduous forest. Deciduous forest is also prominent along bluffs adjacent to the river. Sixteen islands (5 very small) are visible.

Row crop agriculture and pasture (including significant row crop agriculture in the Wabash River floodplain) dominate land use in upland areas, with lessor tracts of deciduous forest and some significant areas of wooded wetlands along tributary floodplains. Several areas

of mining activity, scattered tracts of mixed forest, and a few urban centers (Morganfield and Sebree, KY) are also visible.

Wabash River, IN to Cairo, IL; river miles 848 to 981 (**Figure C-10**, Ohio River at Confluence with Wabash River and **Figure C-11**, Ohio River at Confluence With Mississippi River and Paducah, KY).
The floodplain is narrowed somewhat near Shawnee National Forest southwest of Wabash River but returns to broad floodplain configuration from Paducah to the confluence with the Mississippi River. Limited urban land use occurs in floodplain areas of Paducah, KY and Metropolis and Cairo, IL. Row crop agriculture is the dominant floodplain land use, with significant secondary areas of wooded wetlands and some pasture and deciduous forest. Deciduous forest is also prominent along bluffs adjacent to the river. Nineteen islands (4 very small) are visible.

Upland land use includes a mix of row crop agriculture, pasture and deciduous forest, with significant areas of wooded wetlands in tributary bottomlands and some fairly large blocks of mixed forest. Significant urban land use is visible in areas adjacent to Paducah and at Calvert City, KY.

C.7.3.2 National Resource Inventory (NRI) Data

The NRI is conducted every five years and measures actual use of nonfederal lands. Use categories discussed in this report include cropland (row crops such as corn, soybeans or wheat), pastureland (grazing and hay production), forest land, developed land, and other (primarily federal land plus open water). The category for developed land is intended to identify lands that have been permanently removed from the rural land base and includes: large tracts of urban and built-up land, small tracts (<10 acres) of built-up lands, and land outside of built-up areas that is in roads, railroads and associated rights-of-way (USDA, Dec. 2000). The NRI provides published data at the state level for 1982, 1987, 1992, and 1997. NRI data for the six states in the study area is presented in **Table C-2** and data for groups of counties adjacent to the Ohio River is presented in **Table C-3**.

TABLE C-2
Statewide Land Use Patterns

State	Year	Total Acreage	% Crop Land	% Pasture Land	% Forest Land	% Rural Land	% Developed
IL	1982	36,058.70	68.6%	8.9%	9.9%	89.2%	7.5%
	1987	36,058.70	68.8%	8.2%	10.0%	88.8%	7.9%
	1992	36,058.70	68.8%	7.7%	10.1%	88.5%	8.1%
	1997	36,058.70	68.6%	6.9%	10.5%	87.8%	8.8%
IN	1982	23,158.40	59.5%	9.5%	16.3%	88.5%	7.9%
	1987	23,158.40	60.4%	8.3%	16.4%	88.0%	8.4%
	1992	23,158.40	60.1%	7.9%	16.4%	87.5%	8.9%
	1997	23,158.40	59.5%	7.9%	16.3%	86.7%	9.8%
KY	1982	25,863.40	22.9%	23.0%	40.4%	89.1%	4.4%
	1987	25,863.40	21.9%	22.8%	40.6%	88.1%	5.2%
	1992	25,863.40	21.3%	22.8%	41.0%	87.3%	5.8%
	1997	25,863.40	21.3%	22.0%	41.2%	86.3%	6.7%
OH	1982	26,444.80	47.1%	10.5%	25.2%	86.7%	10.5%

State	Year	Total Acreage	% Crop Land	% Pasture Land	% Forest Land	% Rural Land	% Developed
	1987	26,444.80	46.9%	9.3%	26.1%	85.9%	11.3%
	1992	26,444.80	46.3%	8.8%	26.2%	84.8%	12.3%
	1997	26,444.80	45.2%	7.6%	26.8%	83.5%	13.7%
PA	1982	28,995.20	20.3%	9.0%	53.5%	86.2%	9.7%
	1987	28,995.20	19.8%	8.5%	53.8%	85.5%	10.4%
	1992	28,995.20	19.6%	7.9%	53.2%	84.0%	11.9%
	1997	28,995.20	19.2%	6.4%	53.4%	82.1%	13.7%
WV	1982	15,508.20	7.1%	12.2%	67.1%	88.0%	3.8%
	1987	15,508.20	6.4%	11.3%	68.2%	87.7%	4.0%
	1992	15,508.20	5.9%	10.4%	68.2%	86.6%	4.5%
	1997	15,508.20	5.6%	9.8%	68.2%	85.5%	5.6%
TOTALS	1982	156,028.70	40.9%	12.0%	32.3%	88.0%	7.6%
	1987	156,028.70	40.8%	11.2%	32.7%	87.4%	8.2%
	1992	156,028.70	40.4%	10.7%	32.7%	86.5%	8.9%
	1997	156,028.70	40.0%	9.9%	32.9%	85.4%	10.0%

Source: USDA Dec 2000

TABLE C-3
Land Use Patterns for Counties Along the Ohio River

State	Year	Total Acreage	% Crop Land	% Pasture Land	% Forest Land	% Rural Land	% Developed
IL	1982	1,334.10	50.7%	13.9%	17.8%	82.4%	2.5%
	1987	1,334.10	51.9%	12.2%	18.0%	82.1%	2.6%
	1992	1,334.10	52.3%	11.1%	17.9%	81.3%	2.7%
	1997	1,334.10	51.9%	11.0%	18.3%	81.2%	2.9%
IN	1982	2,646.40	37.0%	16.0%	29.9%	82.9%	7.8%
	1987	2,646.40	37.4%	15.0%	30.0%	82.4%	8.2%
	1992	2,646.40	36.7%	15.0%	29.9%	81.6%	8.5%
	1997	2,646.40	36.7%	14.7%	29.8%	81.2%	9.2%
KY[1]	1982	1,491.50	12.9%	24.4%	50.9%	88.2%	7.5%
	1987	1,491.50	12.6%	23.2%	51.5%	87.3%	8.5%
	1992	1,491.50	11.1%	22.2%	53.5%	86.8%	9.6%
	1997	1,491.50	11.0%	18.3%	55.3%	84.6%	11.5%
KY[2]	1982	3,388.10	36.3%	21.6%	24.6%	82.5%	7.7%
	1987	3,388.10	36.2%	19.2%	26.0%	81.4%	8.8%
	1992	3,388.10	36.0%	17.7%	26.5%	80.2%	9.9%
	1997	3,388.10	34.3%	17.3%	26.7%	78.3%	11.5%
OH	1982	4,494.10	21.4%	16.4%	45.3%	83.1%	8.2%
	1987	4,494.10	21.4%	14.5%	46.8%	82.7%	8.8%
	1992	4,494.10	20.9%	13.9%	46.7%	81.5%	9.5%
	1997	4,494.10	20.3%	11.2%	48.5%	80.0%	10.7%
PA	1982	2,994.50	18.0%	12.6%	47.9%	78.5%	15.8%
	1987	2,994.50	16.7%	12.2%	48.2%	77.1%	17.8%
	1992	2,994.50	16.3%	11.1%	47.0%	74.4%	19.8%
	1997	2,994.50	16.8%	8.2%	46.9%	71.9%	22.6%
WV	1982	2,209.30	10.8%	15.7%	62.8%	89.3%	4.0%
	1987	2,209.30	10.1%	14.7%	64.1%	88.9%	4.3%
	1992	2,209.30	9.0%	14.1%	64.7%	87.8%	4.8%
	1997	2,209.30	8.3%	13.5%	64.9%	86.7%	6.0%
TOTALS	1982	17,223.90	26.7%	17.2%	39.9%	83.8%	7.6%
	1987	17,223,90	26.6%	15.9%	40.7%	83.1%	8.4%
	1992	17,223,90	26.0%	15.0%	40.9%	81.9%	9.3%
	1997	17,223.90	25.6%	13.5%	41.5%	80.6%	10.6%

[1]KY – Boone County and East; [2]KY– West of Boone County
Source: USDA Dec 2000

C.7.3.3 Statewide Data

This data may not be directly comparable to land use patterns along the Ohio River, but should be approximately comparable to data for the Ohio River Valley (ORV). **Table C-3** illustrates the preponderance of cropland in Illinois, Indiana and Ohio and forestland in West Virginia and Pennsylvania. Kentucky has the highest percentage of pastureland and ranks third in forestland. Four of the six states in the ORV (OH, PA, IL, IN) have a

higher proportion of developed area than the national average, which was 6.6% in 1997. For the six-state total, 10.5% of the area was developed as of 1997.

With respect to statewide trends, all six states show significant increases in the amount of developed land. Additionally, the rate of development increases during the reporting period for all six states. Cumulatively for the six states, 0.6% of total land area was developed from 1982 to 1987, 0.8% was developed from 1987 to 1992 and 1.2% from 1992 to 1997 (double the 1982-1987 development rate). The total area of developed land within the six states increased by 32% during the 15 years covered by this data. This compares closely to the national increase of 34% during the same period. Nationally, an average of 1.4 million acres per year was developed from 1982 to 1992. This increased to an average of 2.2 million/year from 1992 to 1997.

It seems likely that the accelerating rate of development illustrated above has continued from 1997 to 2002. Housing construction has not slowed down the past two years, partly because of federal interest rate reductions that have contributed to record low mortgage rates. A conservative estimate would set land developed from 1997 to 2002 as equal to the total developed from 1992 through 1997, or 1.2% of total land within the six states. Thus it is estimated that 11.7% of total land area within the six states has been developed for urban/commercial/industrial use as of 2002.

C.7.3.4 Data for Counties Adjacent to the Ohio River

These data have been grouped to provide regional information for individual segments of the river. NRI data is collected via a sampling protocol and grouping is necessary to avoid distortions due to sampling error that may occur when data is reported for individual counties. Information about the groups of counties adjacent to the Ohio River can be compared to statewide data or to the NLCD92 imagery.

The seven-county area in Illinois that lies adjacent to the river accounts for only 3.7% of the state's total land area. Row-crop land use of 52% reflects extensive use of the broad floodplain for this type of production. Percentages for pasture (11%) and forested (18%) land use reflect the general mixed-use pattern in the upland areas. Only 2.9% of this region is developed, which is consistent with the scarcity of urban/commercial areas in the NLCD92 imagery.

Extensive row-crop agriculture in the broad floodplain of the western Ohio River is also reflected in the cropland percentages for Indiana (37%) and western Kentucky (35%). These counties also reflect a mixed-use pattern of cropland, pasture (IN-15%, KY-18%) and forestland (IN-30%, KY-27%) in areas away from the floodplain similar to the patterns in southern Illinois. Indiana counties adjacent to the Ohio River account for about 11% of the state's land area, while Western Kentucky counties (Gallatin to Ballard) account for about 13% of that state's total.

Development in Indiana's river counties (9.2%) is similar to the state average (9.8%), but reflects a somewhat slower rate of growth over the 15-year reporting period (18% vs. 24%). Western Kentucky's development is well ahead of the state composite (11.5% vs. 6.7%) but the rate of growth is about the same (49% vs. 52.3%). The NLCD92 imagery illustrates the primary growth near Louisville and other growth areas of Owensboro, Henderson and Paducah, Kentucky and Evansville, Clarksville and

Jeffersonville, Indiana. The NLCD92 imagery also illustrates that most urban growth, which originated on the river, is now occurring on inland areas above the floodplain.

Ohio counties adjacent to the Ohio River encompass about 17% of the total area of the state. These counties have almost twice as much forestland as the state average (48% vs. 27%) but less than half the state average for cropland (20% vs. 44%). The developed area of 10.7% is close to the state average of 12.4% and the rate of development (30% vs. 33%) is also close. The NLCD92 imagery illustrates that the Ohio River floodplain is quite narrow throughout most of this stretch and also illustrates the dominance of forest cover except for the Cincinnati urban areas in Hamilton and Clermont counties. The imagery also illustrates the concentration of development within the floodplain in middle and upper reaches of the river in contrast with the rural nature of the surrounding countryside.

Eastern Kentucky counties from Boone to Boyd are quite similar to their Ohio counterparts across the river, with 55% forest cover and 11.5% developed area, although more of the cultivated land is in pasture rather than row crops. These counties account for about 5.8% of total state area and are considerably ahead of the state in terms of developed area (11.5% vs. 6.7%). However, the rate of development is approximately equivalent (53.3% vs. 52.3%). The NLCD92 imagery shows that most of the development is located in the Boone, Kenton and Campbell county area opposite Cincinnati, with a secondary concentration in the Ashland/Greenup area.

West Virginia Counties on the Ohio River account for about 15% of the state's land area and closely resemble statewide averages in all categories. The NLCD92 imagery shows that these counties are heavily forested, with most of the developed and row crop areas concentrated in the floodplain along the river.

Only two counties in Pennsylvania are adjacent to the Ohio River. NRCS data presented here represents the six Pennsylvania counties in the Pittsburgh MSA. As would be expected, the developed area for this metropolitan region is higher than the state average and higher than the mixed urban/rural zones covered by the other county groupings. The overall rate of development (43%) is close to the state average of 41%.

C.7.3.5 Demographic Data

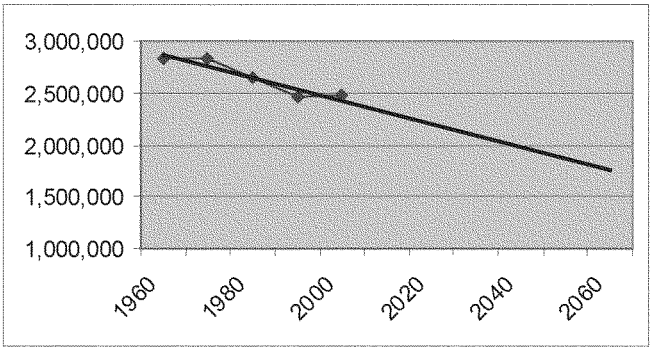
County populations and trends can provide an additional perspective on land use patterns described in the preceding discussions. **Figures C-12 through C-25** illustrate population and trends for Metropolitan Statistical Areas (MSAs) along the Ohio River and for groups of rural counties adjacent to the Ohio River between the metropolitan areas. The trends are simple straight-line projections based on the five data points shown in the figures.

These figures illustrate a dramatic contrast between long-term population declines on the upper river, potentially level trends in the middle reach, and ongoing growth along the lower river.

The population of the Pittsburgh MSA (**Figure C-12**) has been declining steadily from a 1960 peak of 2,838,797 to the 2000 Census population of 2,470,770. The MSA consists of an urban core county (Allegheny) and six outlying counties. Two counties,

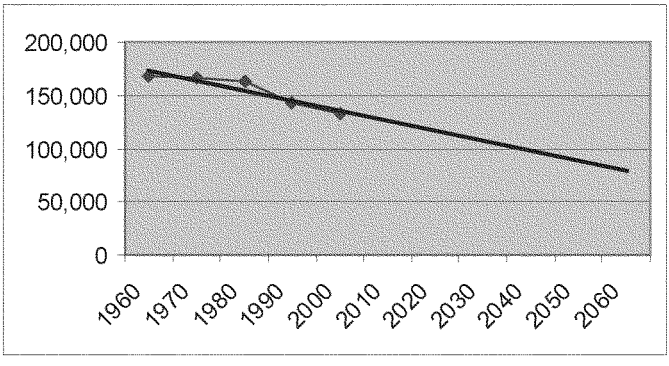
Allegheny and Beaver, are adjacent to the Ohio River. The core county and four of the outlying counties (including Beaver) have been experiencing population declines during 1960-2000. However, the area of developed land use within the MSA has continued to expand in spite of the declining population trend. Between 1982 and 1997, Pittsburgh's developed area grew by 201,800 acres, an increase of 43% (USDA 2000).

FIGURE C-12
Pittsburgh MSA Population Trend



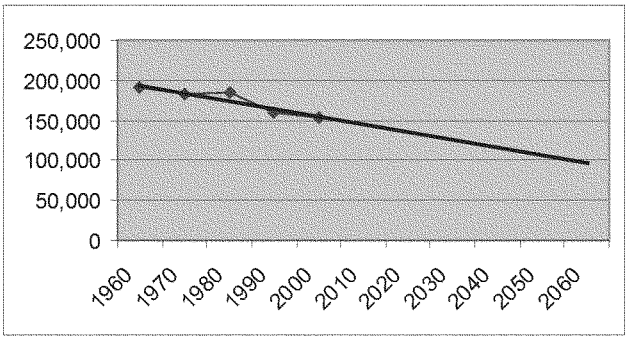
Downstream from Pittsburgh and adjacent to the Pittsburgh MSA, the Steubenville/Weirton MSA (**Figure C-13**) represents three counties in Ohio and West Virginia, all adjacent to the river. The MSA has been declining from a 1960 peak of 167,756 to the current population of 132,008. All counties within the MSA are experiencing general population decline.

FIGURE C-13
Steubenville-Weirton MSA Population Trend



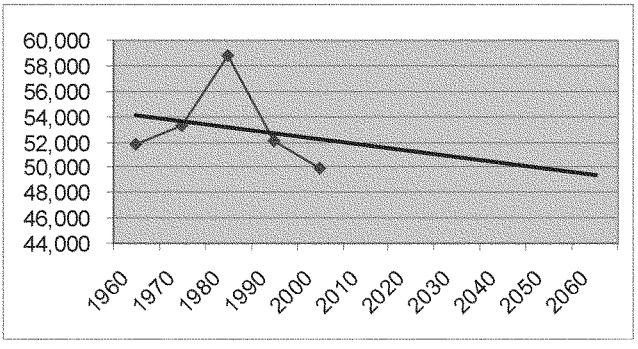
A similar pattern of decline is evident in the Wheeling MSA (**Figure C-14**), which lies downstream of and adjacent to the Steubenville/ Weirton MSA. This MSA also consists of three counties in Ohio and West Virginia that are adjacent to the river and experiencing sustained population declines. The population of the Wheeling MSA peaked in 1940 at 208,918 and now stands at 153,172.

FIGURE C-14
Wheeling MSA Population Trend



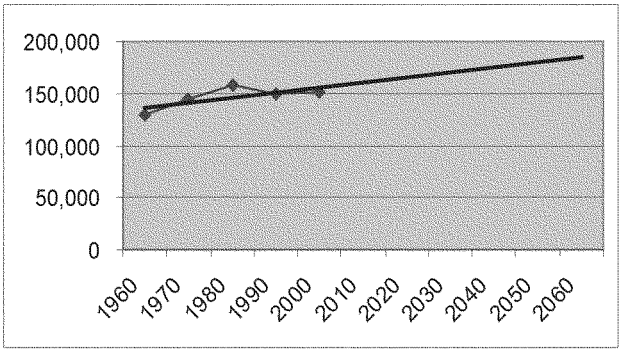
Four rural counties in Ohio and West Virginia are adjacent to the Ohio River between the Wheeling and Parkersburg MSAs (**Figure C-15**). The population of these counties peaked in 1900 at 77,500 and declined to a low of 51,765 in 1960. Population then grew to 58,812 in 1980 before declining again to the current level of 49,979. All four counties show similar growth and decline patterns for the period of 1960 to 2000.

FIGURE C-15
Wheeling to Parkersburg Population Trend



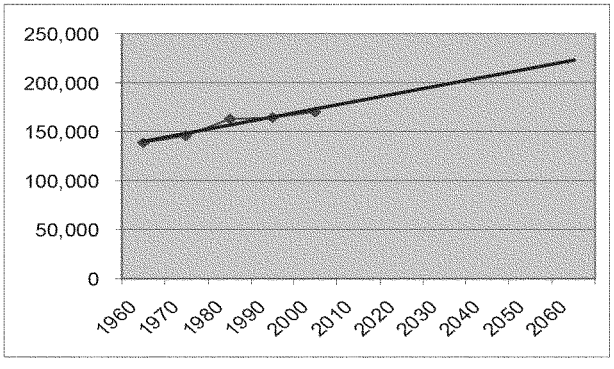
The Parkersburg/Marietta MSA (**Figure C-16**) includes two counties whose populations grew steadily from 1900 to a peak of 157,914 in 1980 before declining to the present population of 151,237. While a trend line from data for 1960 through 2000 suggests continued slow growth for this community, a trend line based on more recent data (1980 through 2000) suggests a level or slowly declining population.

FIGURE C-16
Parkersburg/Marietta MSA Population Trend



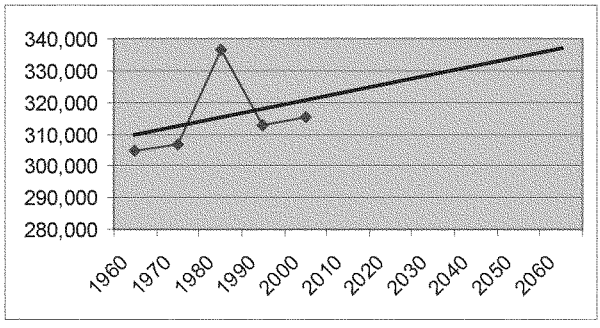
Five rural counties in Ohio and West Virginia are adjacent to the Ohio River between the Parkersburg/Marietta MSA and the Huntington/ Ashland MSA (**Figure C-17**). This area declined slowly from a 1900 population of 142,397 to a 1950 population of 132,812. The area has since experienced gradual but steady growth to its current level of 170,321. This growth is broadly shared by four of the counties, with one remaining approximately level during the 1950 to 2000 period.

FIGURE C-17
Parkersburg to Huntington Population Trend



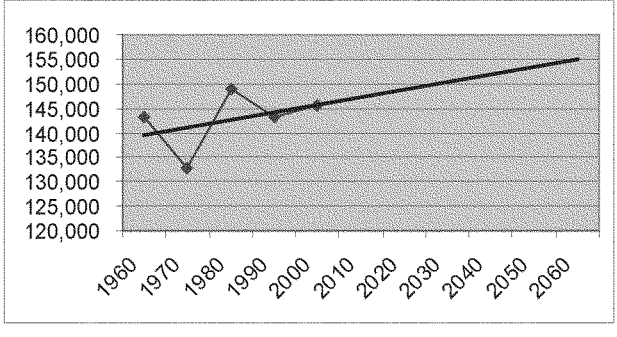
Six counties are included in the Huntington/Ashland MSA (**Figure C-18**), five of which border the Ohio River. Long term growth in this area continued from 1900 to a peak of 336,410 in 1980 before declining to the current population of 315,538. All six counties share the same general growth/decline pattern from 1960 to 2000, which also closely resembles the pattern for counties between Wheeling and Parkersburg.

FIGURE C-18
Huntington/Ashland MSA Population Trend



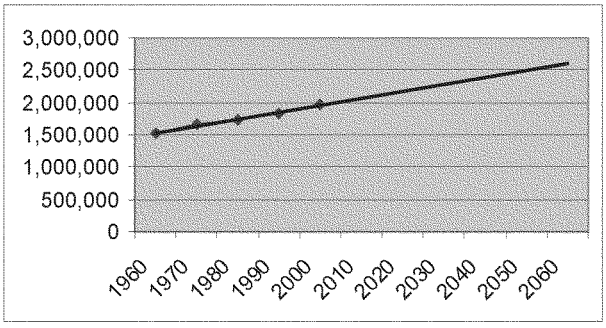
Five rural counties in Ohio and Kentucky are adjacent to the Ohio River between the Huntington/Ashland MSA and the Cincinnati Consolidated MSA (CMSA) (**Figure C-19**). These counties experienced a long-term growth trend that peaked in 1950 at 152,411. This was followed by a decline to 1970 before experiencing the 1980 peak and decline pattern that resembles the pattern experienced by the Huntington/Ashland MSA and the Wheeling to Parkersburg counties. However, the trend is not evenly distributed among all counties within this group. Adams County grew from 24,328 to 27,330 between 1980 and 2000, while most of the population decline occurred in Scioto County, which fell from 84,595 to 79,195.

FIGURE C-19
Huntington to Cincinnati Population Trend



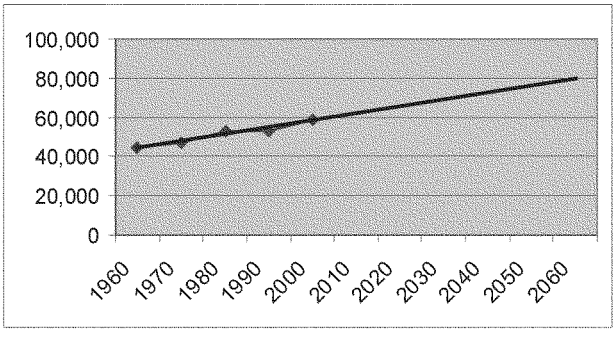
The upstream pattern of short-term volatility around a longer trend of stable or slowly declining population appears to end at the Cincinnati CMSA (**Figure C-20**). Cincinnati contains a core urban county surrounded by twelve outlying counties, all but three of which border the Ohio River. The CMSA has experienced sustained growth throughout the period from 1900 to 2000, growing from 741,031 to 1,979,202. However, the central county peaked in 1970 at 924,018 and has declined each succeeding decade to 845,303 in the 2000 census. All outlying counties have experienced growth from 1980 to 2000, but the majority has been concentrated within the three Ohio and three Kentucky counties that constitute the inner ring of adjacent counties.

FIGURE C-20
Cincinnati CMSA Population Trend



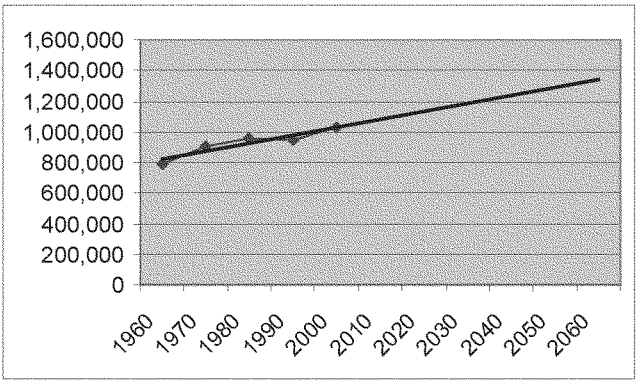
Four rural counties in Kentucky and Indiana are adjacent to the Ohio River between the Cincinnati CMSA and the Louisville MSA (**Figure C-21**). These counties declined from a peak population of 51,850 in 1900 to a low of 41,117 in 1930 and remained approximately level through 1950. All of the counties have since experienced gradual but steady growth, reaching a 2000 total of 59,050.

FIGURE C-21
Cincinnati to Louisville Population Trend



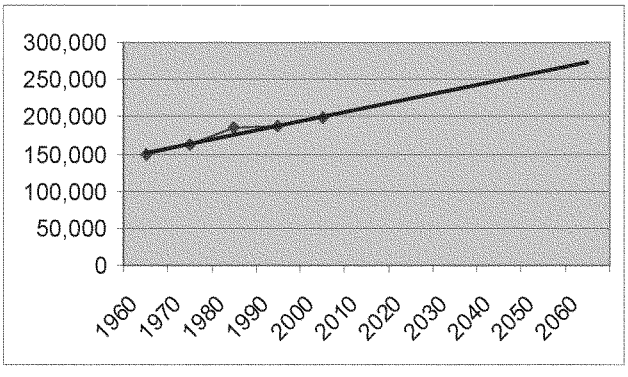
The Louisville MSA (**Figure C-22**) includes a core county and six outlying counties which have collectively experienced sustained growth from 341,191 in 1900 to 1,025,598 in 2000. Jefferson County (the core) peaked at 695,055 in 1970, declined to 664,937 by 1990, then recovered to 693,604 in the 2000 census. Growth in the outer counties is generally dispersed through five of the six counties, although all are experiencing growth.

FIGURE C-22
Louisville MSA Population Trend



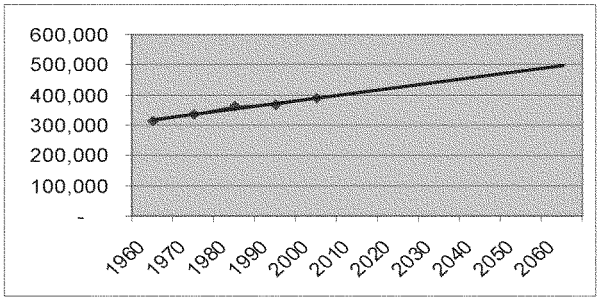
The river reach from Louisville to Evansville (**Figure C-23**) includes seven rural counties in Kentucky and Indiana adjacent to the Ohio River. These counties declined from 117,579 in 1900 to a low of 95,968 in 1930, then grew strongly to a total of 184,901 in 1980. Slower growth has continued to the present population of 197,596. Growth is broadly distributed among the counties, although Hardin County, KY, which includes Ft. Knox, accounts for about 48% of the total population.

FIGURE C-23
Louisville to Evansville Population Trend



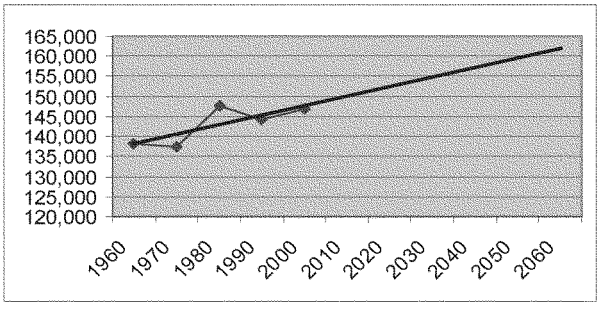
The Evansville MSA (**Figure C-24**) encompasses five counties and includes the MSAs for Owensboro and Henderson, KY. All counties in this area have shared in steady growth dating from a population of 188,005 in 1900 to 387,740 in the 2000 census. Evansville, IN functions as the 'urban core' for this area, with a 2000 population of 171,922.

FIGURE C-24
Evansville MSA Population Trend



Below Evansville (**Figure C-25**) are ten rural counties adjacent to the river in lower Illinois and western Kentucky. Collectively, these counties experienced a fairly stable population of about 155,000 from 1900 to 1940, then declined to 137,347 in 1970. This area experienced a peak and decline pattern between 1970 and 1990 that resembles the pattern experienced by several areas on the upper and middle portions of the river. However, collective numbers for this group mask broad disparities among individual counties. McCracken County (Paducah, KY) shows steady growth through every decade since 1900 and now accounts for 45% of this area's population at 65,514. Eight of the ten counties show net population declines from 1900 to the present and several now have less than half of their original 1900 populations. From 1960 to 2000, three of the five Illinois counties experienced declining populations, one has been stable, and one experienced moderate growth from 14,341 to 15,161. The other four Kentucky counties have experienced stable to slight population growth for the same period.

FIGURE C-25
Population Trend below Evansville



C.8 INTERACTIONS WITH OTHER VECS

The existing land use patterns within the floodplain create opportunities and impose restraints on potential future activities. The free-flowing river of the 1920's has been replaced by a series of 20 slackwater pools and general hydrology of the river is controlled by the navigation dams, upstream flood control reservoirs, and levee and floodwall construction in numerous communities along the river. In the upper river from Pittsburgh to Parkersburg, fill material (often slag from iron and steel operations) was used to create significant areas of elevated land along the river, which resulted in the loss of floodplain within the filled areas.

There are numerous environmental implications of various land uses. For example, nonpoint pollution (e.g., nutrients) from agricultural land will differ from that associated with industrial zones or residential areas. The timing and quantities of storm water discharges also change with the increase of impervious surfaces in developing areas. Noise levels also differ with land use as do air pollutant emissions. Further, infrastructure demands (roads, water supply, sanitary sewer lines, and storm water sewers) also vary with land use categories. The implications of these changes need to be considered when addressing the environmental consequences of land use changes.

Within the physical landscape described above, the current patterns and trends of settlement and development define the context of ongoing land use impacts. Numerous business and economic forces influence population growth or loss, and related economic and land use changes, along the Ohio River mainstem. The navigation system and its associated economic influences are one such force in the overall land use patterns of the corridor.

The relationship between the navigation system and current and future land use patterns can be reviewed in various ways. One can address the contribution of the navigation system to the current physical landscape of the river and the network of economic activities that benefit from this system. This is an ongoing contribution as excess capacity for commercial traffic growth facilitates future industrial growth. The navigation system can also be viewed as a potential tool for management of the Ohio River. In concert with management of upstream flood control reservoirs, navigation dams could be used to manipulate river flows to improve habitats, minimize damaging impacts, or achieve other desired land use outcomes.

C.9 RELEVANT ACTIONS AFFECTING LAND USE

Reasonably Foreseeable Future Actions (RFFA) were evaluated using the RFFA Matrix (see Chapter 2 for discussion of RFFA matrix). The matrix evaluation process resulted in identification of 31 RFFAs with potentially high importance to future land use patterns and 27 RFFAs with medium importance. These RFFAs are presented in **Table C-3**.

RFFAs likely to be of high importance to future land use patterns include:

- the activities of proactive interest groups
- government regulations and programs
- ongoing industrial and commercial activities that are oriented to the river and/or barge transportation, and

- actions affecting key infrastructure that can influence the feasibility of certain types of development.

Proactive interest groups identified in the RFFA Matrix represent six categories of water-based recreation: boating, fishing, personal watercraft (PWCs), hunting, wildlife watching, and sight-seeing. The importance rankings are based on the assumption that these recreational users are likely to take a proactive interest in land use decisions affecting their resource of interest. Although not explicitly recognized in the RFFA Matrix, interest groups represented by environmental and resource conservation oriented organizations are also likely to be of high importance to public decision processes affecting future land use patterns.

Government regulations and programs currently exert very little direct influence over land use patterns, but have the potential to be a key influence if there is enough public support for such approaches. Activities with potentially high importance include site remediation, more stringent environmental standards, wetland mitigation banking, farmland preservation, Corps permitting programs, endangered species act, and public funding of recreation facilities, parks and preserves. Activities given a medium importance ranking include Phase 1 and 2 NPDES programs, pollutant source control, carbon sequestration, and environmental awareness education.

Industrial and commercial activities associated with the river and/or river transportation include; mining (instream or floodplain), coal utilities and industries, other industrial activities, agriculture, and silviculture. These activities have constituted the dominant force shaping past land use patterns along the river and are expected to continue to play an important role in future land use issues. Industrial development is the primary land use on floodplains and terraces of the upper river, agriculture is the primary land use on floodplains and terraces of the middle and lower river, and silviculture is the primary land use on adjoining slopes along the length of the river.

Infrastructure development in and around the Ohio River has been the key element necessary to creating opportunities for commercial, industrial, and residential development. In many cases, key infrastructure plays a direct role influencing subsequent land use patterns. Categories expected to continue to be of high importance include; bridges, marinas, levees/floodwalls, ports, and marinas.

TABLE C-3
RFFA Cumulative Effects Matrix for Land Use VEC

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Land Use - Impacts
Navigation Investment Actions					
Lock Extensions/New Locks/Replacement or Rehabilitation	Corps planning (districts); ORNIM study outputs	A	H	SL	M
L&D operation and maintenance	Corps O&M records, J.T. Myers & Greenup Locks Improvements EIS	A	H	SL	M

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Land Use - Impacts
Other Corps Actions					
Channel dredging/dredged material disposal	Corps (districts), J.T. Myers & Greenup Locks Improvements EIS	A	H	E	M
Flood damage reduction projects					
levees/floodwalls	EAs and EISs from individual communities, Corps O&M records, ERP projects list	A	L	E	H
dry dams, other projects off mainstem	EISs in Corps planning offices (districts), projects planned on tributaries	A	L	SL	M
channel modifications	Point Pleasant project, projects planned on tributaries	A	H	SL	M
nonstructural measures (relocation)	FEMA, flood relocation reports, Corps planning, Mill Creek project	A	H	SL	M
Emergency streambank stabilization (Sec. 14)	Corps planning & operations (districts)	A	H	E	M
Modification of Corps structures for environmental improvements (Sc. 1135)	Corps planning & operations (districts)	A	M	SL	M
Environmental restoration of aquatic ecosystems (Sec. 206)	Corps planning & environmental offices (districts), EA for ERP	A	M	SL	M
Recreation facilities - Construction and O&M	Corps recreation planning, and operations (districts), navigation charts	A	H	SL	M
ERP Projects - 5 categories	EAs for ERP divided by habitat type	A	M?	SL	H
Port development (Sec. 107) and maintenance dredging	Corps planning , operations & historic records, state port authorities, navigation charts, state transportation plans	A	H	SL	H
"But for" Actions					
Commercial Navigation					
terminals	Navigation charts, Sec.401 & 404 permits, Mangi questionnaire	A	H	SL	H
multi-modal sites	Navigation charts, riverfront development plans, Mangi questionnaire, state transportation improvement plans	A	H	SL	H
increased traffic	Corps traffic forecasts by Huntington economics group	A	H	E	M
Instream sand and gravel mining	State mineral extraction agencies, navigation charts (?), 1981 Corps EIS, Corps economics group (Huntington)	A	H	SL	H
Floodplain sand and gravel mining	State mineral extraction agencies, navigation charts, aerial photos	A	H	SL	H
Limestone aggregates mining	State mineral extraction agencies, navigation charts, aerial photos, National Mining Association	A	H	SL	H
Coal utilities	DINAMO, Corps economics team (Huntington), state utility regulators, NPDES permit holders	A	H	SL	H
Other coal industries	DINAMO, Corps economics team (Huntington), state utility regulators, NPDES permit holders	A	M/L?	SL	H
Industrial users, excluding coal-related	ORSANCO , NPDES permits	A	H	SL	H

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Land Use - Impacts
Recreation facilities - Construction and O&M	State tourism offices, DNRs, SCORPs, Land & Water Conservation Fund	A	H	SL	H
Actions by Others					
Park development and operations	OR Island National Wildlife Refuge EIS & Plan, state park planners, Nature Conservancy, Audubon, Land & Water Conservation Fund, Pt. Pleasant Riverfront Park Feasibility Study	A	H	E	H
Public forest development and operations	Forest Land & Resource Mgmt. Plans, state forest plans, Land & Water Conservation Fund	A	H	SL	H
Floodplain development					
residential	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,	A	H	SL	M
commercial	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,	A	H	SL	M
industrial	Riverfront development plans, county comprehensive plans, Corps economics group (Huntington), LANDSAT images, FEMA floodplain map revisions, demographic data, historic trends,	A	H	SL	H
Crossings					
bridges	State long-term transportation plans, KY bridges and Corridor D (WV) web sites, navigation charts, EISs, River Fields (Louisville) web site	A	H	SL	H
Marina development & operation	navigation charts, historic trends, LANDSAT images, Sec.404 & NPDES permits	A	H	SL	H
Water -based recreation					
boating	State registration agencies, recreation surveys	A	H	E	H
fishing	State resource agencies, recreation and creel surveys	A	H	E	H
PWCs	State boat registration agencies, recreation surveys	A	H	E	H
hunting	State resource agencies, recreation surveys	A	H	SL	H
wildlife watching	State resource agencies, NAWMP, recreation surveys, environmental groups	A	H	E	H
sight-seeing	State tourism offices, recreation surveys	A	H	E	H
Silviculture	NRCS, state resource agencies, woodland management associations	A	H	SL	H
Agriculture	NRCS, state agricultural agencies, aerial photos	A	H	SL	H
WWTP discharges					
municipal	ORSANCO, navigation charts, NPDES permits, state regulatory agencies	A	H	SL	M
Stormwater discharges	Stormwater mgmt. utilities, Phase 1 & 2 communities, exempt communities with CSOs	A	H	SL	M

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Land Use - Impacts
	and SSOs				
Brownfields redevelopment	Riverfront dev. plans, port authorities, federal and state brownfields redevelopment funding authorities	A	H	SL	M
Trail/bikeway development	Regional planning organizations., state tourism offices, Rivers, Trails & Con. Assistance program, state transportation plans	A	H	E	M
Casinos	State gaming commissions	A	H	SL	M
Hazardous waste sites	HAZMET inventory	A	H	SL	M
Natural Climatic Events					
floods	Historical data from Corps, FEMA, state climatology agencies	A	H	E	M
Regulatory Environment					
Phase I & 2 NPDES program	USEPA Regulatory Agenda Updates, state agencies administering program, CWA amendments	A	H	SL	M
Site remediation	USEPA Regulatory Agenda Updates, amendments to RCRA, CERCLA & SARA, new or amended state laws	A	H	SL	H
More stringent quality standards for environmental	USEPA Regulatory Agenda Updates, amendments to CAA, CWA, SWDA & RCRA, state agencies administering federal and state environmental media laws	A	H	E	H
Pollutant source control	USEPA Regulatory Agenda Updates, amendments to CAA, CWA, SWDA & RCRA, state agencies administering federal and state environmental media laws	A	H	E	M
Wetland Mitigation Banking	Updates to federal guidance by Corps, USEPA, NRCS, USFWS and NOAA; Institute for Water Resources)	A	H	SL	H
Carbon sequestration	US Dept. of Energy	2,3	M	E	M
Farmland preservation	Policy updates from NRCS, amendments to federal Farm Bills, state agriculture or natural resource agencies	A	H	SL	H
Effluent trading	Policy and/or regulatory updates from USEPA, amendments to CWA; ORSANCO, state water and/or pollution control agencies	A	H	SL	M
COE permitting programs	Corps (3 districts, division, and headquarters), amendments to CWA, WRDA and other pertinent laws	A	H	E	H
Small navigation projects	Corps (headquarters), amendments to RHA and WRDA	A	H	SL	M
Environmental Awareness Education	USEPA policies and programs, educational components of CWA, SDWA, CAA, RCRA, ESA and natural resources laws (current or based on amendments), state programs	A	H	E	M
ESA (Endangered Species Act)	Policy and/or regulatory changes of USFWS, amendments to ESA, USFWS candidate species list, recovery plans, OR Valley Ecosystem Team, biological assessment for ORMSS	A	H	SL	H

RFFA[1]	Sources[2]	Time Period[3]	Occurrence Probability[4]	Location on River[5]	Land Use - Impacts
Environmental sustainability practices	President's Council on Sustainable Development, environmental NGOs	2,3	M	E	M

[1] Reasonably Foreseeable Future Actions

[2] Plans, regulations, sampling data, maps, trend analyses, etc.

[3] Time period in which the RFFA may occur: 1 = within 10 years, 2 = in 10 - 25 years
3 = in 25 - 60 years, A=all time periods

[4] Occurrence probability or likelihood RFFA will happen: H = high M=medium L= low

[5] Location or setting on river where RFFA is expected to occur: U = upper (Pittsburgh - Huntington)
M = middle (below Huntington - Louisville) L = lower ((below Louisville - mouth)
E = along entire length of river SL = specific location U = urban setting R = rural setting

C.10 CUMULATIVE EFFECTS: PAST TO CURRENT AND REASONABLY FORESEEABLE FUTURE ACTIONS

An initial attempt at describing near term land use patterns assumes that current trends will continue with minimal change. With respect to population projections for specific areas, this approach assumes that changes over the next twenty years or so will be about the same as the past twenty to forty years. For land use patterns, a possible assumption is that rates at which land has recently been developed provide a reasonable indicator of trends for the near future. While these are very simplistic assumptions, they at least provide a picture of the near future that may inform further assumptions and analysis.

Population and land use trends through 2020 are presented in **Table C-4 and Figure C-26**. Land areas included in the table are the counties adjacent to the Ohio River as previously described in the Baseline Conditions section. Two population projections are presented, one based on average changes over the past 40 years (5 data points), and the other based on average changes for the past twenty years (3 data points). For the overall study area, these result in net growth projections of 1% to 3%. Projections for individual areas vary from –11% for counties in West Virginia adjacent to the river to a maximum of 16% for Eastern Kentucky counties.

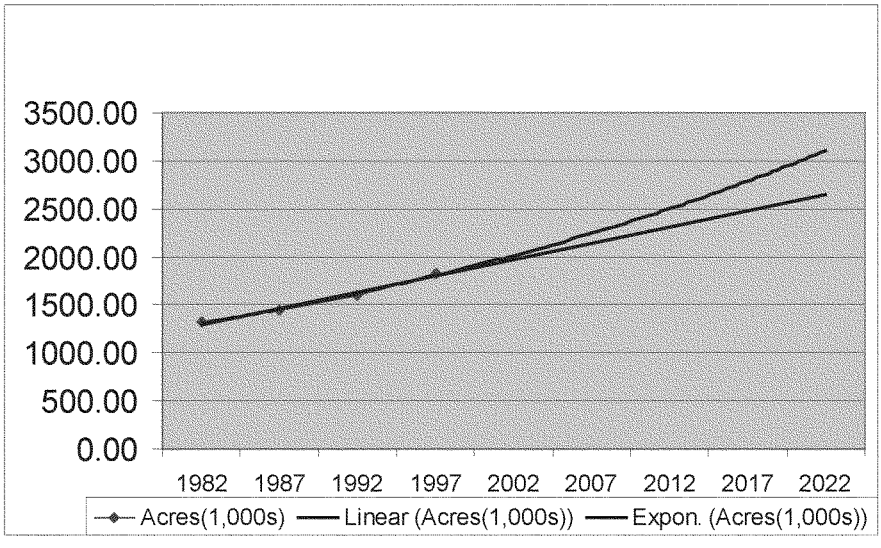
The figures for developed area represent the percentage of total land in each group of Ohio River counties that were reported as developed by the NRCS National Resource Inventory for 1982, 1992 and 1997. The land use projections assume a linear progression based on the average rate of change for the reporting period of 1982 to 1997. This is a conservative estimate compared to the accelerating rate of development represented by an exponential progression of the data (**see Figure C-26**). For the overall study area, the linear assumption predicts that 15.6% of the total land surface in the study area will be developed by 2022.

TABLE C-4
Population and Land Development Projections in Study Area Counties

State	1960	1980	2000	2020(60)	2020(60)	2020(80)	2020(80)
Pennsylvania	2731793	2529695	2358695	2,197,624	-7%	2,199,254	-7%
Ohio	1846555	2043903	2176589	2,371,099	9%	2,317,889	6%
West Virginia	480040	515305	457489	446,743	-2%	406,160	-11%
Kentucky East	393976	455109	523418	609,403	16%	601,980	15%
Kentucky West	959850	1141195	1211860	1,370,948	13%	1,286,901	6%
Indiana	462304	558648	618481	722,950	17%	684,722	11%
Illinois	42409	41207	38167	36,258	-5%	35,351	-7%
Total	**6,916,927**	**7,285,062**	**7,384,699**	**7,634,402**	**3%**	**7,485,699**	**1%**
State	**DV 1982**	**DV 1992**	**DV 1997**	**DV 2002**	**DV 2007**	**DV 2012**	**DV 2022**
Pennsylvania	15.8%	19.8%	22.6%	24.9%	27.1%	29.4%	33.9%
Ohio	8.2%	9.5%	10.70%	11.5%	12.4%	13.2%	14.9%
West Virginia	4.0%	4.8%	6.0%	6.7%	7.3%	8.0%	9.3%
Kentucky East	7.5%	9.6%	11.5%	12.8%	14.2%	15.5%	18.2%
Kentucky West	7.7%	9.9%	11.5%	12.8%	14.0%	15.3%	17.8%
Indiana	7.8%	8.5%	9.2%	9.7%	10.1%	10.6%	11.5%
Illinois	2.5%	2.7%	2.9%	3.0%	3.2%	3.3%	3.6%
Total	**7.6%**	**9.3%**	**10.6%**	**11.6%**	**12.6%**	**13.6%**	**15.6%**

Source: US Census 2000 and USDA, 2000.

FIGURE C-26
Land Development Projections in Ohio Corridor



Source: USDA 2000.

The simplest assumption, that current trends will continue for the next twenty years or more, also serves to illustrate where the ongoing development will occur. The heaviest concentrations of new residential and commercial development will be in counties adjacent

to the major urban core counties of Louisville, Cincinnati and Pittsburgh. All of the counties in the Evansville/Henderson/Owensboro area would be expected to continue their current growth. At a more local level, specific patterns of growth will follow the expansion of infrastructure, including new roads, sanitary sewer service, and new interchanges on limited access highways. These patterns are well illustrated in the NLCD92 imagery.

Some development impacts can be predicted to concentrate in specific areas within the floodplain. Such areas would include locations for the expansion of commercial navigation infrastructure: multimodal terminals, areas for storage and transfer of bulk materials, highways and rail spurs to connect the multimodal functions. Other floodplain developments would include mining activities, and general expansion of existing types of industrial activities. New residential and commercial growth would be primarily located on higher terraces or in areas protected by floodwalls and levees. Growth of marinas and other recreational facilities would be concentrated in embayments. Some of this development activity has the potential to revive or renovate underused urban space or industrial brownfields areas, but much of it will involve the conversion of existing floodplain land uses: agriculture, riparian woods, and wetlands.

As these development pressures increase, opportunities to protect habitat, open space and ecosystem function values, such as those identified in the Ecosystem Restoration Program, will become scarce and expensive. Well funded, proactive conservation programs will become increasingly more important to achieve protection of the dwindling resources.

As discussed elsewhere in this report, the existing commercial navigation system has sufficient excess capacity to accommodate traffic growth resulting from predicted economic growth in the region. In other words, the existing commercial navigation system would continue to support similar types and patterns of land use development as have occurred since completion of the high lift system. Lock expansions and other transportation efficiency improvements addressed in the SIP would reduce delays associated with repair events, but would have no perceptible impact on the broader pattern of economic development and therefore would have no impact on broad land use patterns.

C.11 ASSESSMENT OF EFFECTS

This section discusses land use impacts that may result from continued operation of lock and dam projects on the Ohio River. The discussion includes direct actions such as lock construction and maintenance, navigation system operation and maintenance, commercial navigation, recreation and other activities. Such actions meet the "but for" criteria to the extent they are dependent on continued operation and maintenance of the navigation system. Indirect actions include activities which may derive some benefit from the existence of the improved navigation system, but would likely have developed regardless of navigation system improvements and would be expected to persist with or without maintenance or additional improvements to navigation. Potential impacts from each class of activities are summarized.

C.11.1 Actions by Corps of Engineers

C.11.1.1 Construction of Lock Chamber Extensions

Specific land use impacts were addressed in the EIS documentation prepared for the Greenup and J.T. Myers locks extension projects. This information can be used as a first step towards assessing the cumulative land use impacts that may result from construction of projects described in the SIP.

Most land use impacts identified for Greenup and Myers were considered to be temporary. The improvements would not be expected to directly displace or alter existing land uses on a permanent basis. For example, construction of the proposed improvements would not be expected to require or result in the permanent loss or conversion of prime farmland or other important agricultural uses. At both locations, sufficient government owned property was available to support all construction-related activities on-site. Following the completion of construction, areas used for construction activities, access roads, temporary material storage and disposal sites and an on-site concrete batch plant would be restored to their original land uses (recreation, wooded habitats). Further, since construction jobs at the lock would be temporary, the need for additional housing would not be expected. Thus, the presence of workers during construction would not be expected to precipitate changes in existing land use patterns.

Any additional lock extension projects that may occur over the 60-year study period would be distributed over the 900+ mile length of the Ohio River. It seems reasonable to assume that time and distance would isolate the temporary impacts of individual projects sufficiently to preclude any permanent land use impacts.

Permanent impacts associated with Greenup & Myers concerned the disposal of excavated and dredged materials resulting from the construction project. The Myers project estimated that 900,000 cu. yd. of material would require 20 acres filled to a depth of seven feet. The Greenup project estimated that 20 acres filled to a depth of ten feet would be required. Both projects addressed a variety of in-river, on-site, and off-site disposal options. These options included creation of in-river aquatic habitats, treatment of disposed materials to reestablish prior use of the disposal site, and conversion of the site from farmland to woodland.

The potential issue of special waste classification of the dredged material was discussed, although it was not expected to be applicable to either site. Kentucky defines special waste as "wastes of high volume and low hazard which include, but are not limited to, mining waste, utility wastes, sludge from water or wastewater treatment facilities, cement kiln dust, gas and oil drilling muds, and oil production brines." If classified, the wastes would have to receive special handling and would be disposed of in a permitted facility.

Some of the proposed disposal sites were located within the 100-year floodplain of the Ohio River. However, there was no discussion of whether this issue affected the disposal options.

The cumulative issue of excavated and dredged materials disposal may have some similarities to potential on-land disposal of materials from channel maintenance dredging. Feasible solutions from one activity may be applicable to the other.

C.11.1.2 Lock Maintenance, Repair, and Rehabilitation

Ongoing commercial use of the lock and dam facilities will require periodic upkeep and maintenance. This will include major and minor repairs of both the (existing) primary locks and the auxiliary locks. As the existing locks age, the need for such repairs will become more frequent. The frequency of repairs will also increase in proportion to ongoing increases in the amount of commercial traffic (and resultant use of the lock chambers) on the Ohio River. For the 60-year study period, these repair events are expected to occur on an average of once every five years for each lock and dam project ($USACE_a$).

Each lock repair event will produce similar but smaller scale temporary impacts on government owned land for parking, maintenance, and lay-down yards. However, maintenance and repair activities would not be expected to require the disposal of significant quantities of dredged or excavated materials.

Maintenance and repair events will continue to occur following completion of lock extensions. However, completion of lock extensions can reduce repair activities and associated land use impacts in three ways. First, it may be feasible to schedule each lock extension so as to eliminate one complete auxiliary chamber repair event. Second, each extension creates a lock in new condition, allowing for a longer time interval between the auxiliary chamber repair events. Finally, the original full-sized lock will be used less, since total lockages can be shared equally between the two full sized locks allowing for a longer time between the main chamber repair events ($USACE_{a1}$, Sept. 2000). Effects from major lock rehabilitation would be similar to those of repairs, but would likely occur over longer periods of time.

C.11.1.3 Nonstructural Navigation Improvements

Nonstructural navigation improvements refer to project alternatives that do not involve lock and dam infrastructure. These include efficiency measures such as vessel scheduling and prioritization, self-help coordination among towboat coordinators and expanded mooring facilities near locks and dams. Some measures, such as expanded mooring facilities, may require modest, temporary land use impacts during construction and installation. Other measures such as vessel scheduling may require improved communication and position tracking systems, but would have no direct land use impacts. It is expected that nonstructural navigation improvements will be implemented wherever they prove to be feasible, independently of other lock extension or repair scenarios.

C.11.2 Other Direct Actions by U.S. Army Corps of Engineers

The Corps conducts a wide variety of other activities within the Ohio River. Activities with potentially significant land use impacts include: major rehabilitation of the dams, channel maintenance dredging, construction of levees or floodwalls, channel modifications for flood control, nonstructural flood reduction programs such as relocation of threatened housing, emergency streambank stabilization (Sec. 14), modification of

Corps structures for environmental improvements (Sec. 1135), environmental restoration of aquatic ecosystems (Sec. 206), construction and operation of recreation facilities, Ohio River Ecosystem Restoration Program (ERP) projects, and port development and maintenance dredging.

The largest of these activities involves major rehabilitation of the dams (as opposed to rehabilitation of lock chambers). While the timing of rehabilitation projects is subject to numerous variables, this activity primarily corresponds to the useful life cycle of the dam. Of the 20 dams currently on the river, 6 have been rehabilitated in the past two decades, at an average age of 60 years following their initial construction. Assuming a life cycle of 60 years, all of the dams currently on the Ohio River may require major rehabilitation during the 60-year cycle of the study period.

Land use impacts from dam rehabilitation projects will be similar to construction site impacts described previously for lock extension projects. The activities will require similar temporary impacts for construction parking and lay down yards and would likely entail similar needs for the disposal of dredged materials.

Channel maintenance dredging involves the removal and disposal of sand and gravel deposits from the navigation channel of the Ohio River to maintain a nine-foot depth. Dredged materials from the upper river are disposed on upland sites. Past practices in the middle and lower river have generally utilized in-stream disposal of dredged materials and thus had minimal land use impacts. However, potential future constraints on in-stream disposal may require use of upland sites for disposal of these dredged materials. Alternatively, dredged materials may be utilized in some cases to create new land or instream structure (sandbars, islands) or supplement losses to existing structure within the river. These ongoing activities will occur independently of lock maintenance or extension activities.

The construction of levees and floodwalls had significant historic impacts that contributed to the present day distribution of urban/commercial developments in floodplains. However, it seems unlikely that significant additional lands will be affected by new floodwall/levee projects. There is also a low probability of retiring any of the current system of flood reduction structures.

The following activities each constitute a significant potential of land use impacts that is dependent on the scope of future projects:

- Channel modifications for flood control
- Nonstructural flood reduction programs
- Emergency streambank stabilization (Sec. 14)
- Modification of Corps structures for environmental improvements (Sec. 1135)
- Construction and operation of recreation facilities
- Ohio River Ecosystem Restoration Program (ERP) projects
- Port development and maintenance dredging

C.11.3 Direct Actions by Others

C.11.3.1 Commercial Navigation

The full spectrum of commercial navigation activities constitutes one of the most significant sources of impacts on land use patterns within the Ohio River floodplain. This is primarily reflected in the hundreds of terminals, intermodal operations, and integrated port facilities located along the full length of the Ohio River floodplain. These facilities transfer coal, limestone, sand & gravel, gypsum, grains, petroleum, chemical stocks, and other bulk materials, as well as providing for interim storage of materials in transit. The quantity of materials shipped on the Ohio River has grown steadily since the 1920's and is expected to continue to grow for the foreseeable future. This continued growth will require new terminals, expanded capacity at existing terminals, and expanded land based storage and transfer facilities, all of which will contribute to ongoing land use changes within the floodplain.

Continued expansion of existing facilities and the establishment of new facilities can be expected to occur in response to general economic/population expansion and subsequent growth in loads carried by barge transport. Traffic projections prepared by the Corps indicate that barge traffic growth will occur independently of navigation improvements addressed by this study. The second generation of high-lift lock and dam projects, which was largely completed in 1980, provides sufficient capacity to meet most of the projected barge traffic growth (see Transportation chapter). Therefore, it can be expected that expansion or addition of barge loading facilities will occur independently of navigation improvements.

Barge queuing is an aspect of commercial navigation that is an important factor to several VECs (see the Air Quality and Aquatic chapters) because of the environmental impacts of such activity. Queuing occurs as a result of both lock extension and lock repair activities, which are referred to as construction delay queuing. Queuing also occurs during heavy traffic when locks are in normal operation (operational delays). However, queuing activities are expected to have no significant land use impacts.

C.11.3.2 Mining Activities

Significant impacts to floodplain land use patterns result from mining activities along the Ohio River. These include instream sand and gravel mining, floodplain sand and gravel mining, and floodplain limestone aggregates mining. Continued growth of such activities is expected to occur in proportion to ongoing population and urbanization/development growth along the Ohio River. These mining activities tend to congregate along the river in areas proximate to growing metropolitan areas or in support of major construction projects such as Olmsted dam or major highways.

Mining activity along the Ohio River benefits directly from the availability of barge transport. If such transport were not available, some mining activity would be replaced by mine sites in other locations. Thus, mining activity at least partially meets the 'but for' criteria. However, capacity within the existing navigation system is adequate to

accommodate any anticipated growth of mining activity and no additional growth would be expected as a result of the navigation improvements addressed by this study.

C.11.3.3.Industrial Activities

A number of industrial activities congregate along the Ohio River or its major tributaries and benefit directly from the availability of barge transport and/or availability of water supplies associated with maintenance of the navigation pools. While some of these activities are conducted within major urban centers, much is dispersed through less populated areas along the length of the floodplain. These include coal-fired electric utilities, other industries utilizing coal as a fuel and/or process material, and other industries with bulk transport needs. Continued growth of these industries is expected to occur in proportion to ongoing population and urbanization/development growth within the broader economy of the Ohio Valley region or the nation at large.

These industrial activities account for the majority of projected growth in barge transport on the Ohio River system. In fact, coal transport alone currently accounts for more than 55% of all barge traffic on the Ohio River and is projected to account for a larger percentage of traffic for the foreseeable future.

C.11.3.4 Recreational Activities

Recreational activities and the infrastructure of marinas, parks, and other support facilities also significantly impact land use patterns within the Ohio River floodplain. The recent rate of growth appears to outpace population and development growth rates and is expected to continue to do so for the foreseeable future. Marina facilities tend to be located in embayments and can be found throughout the floodplain, although they concentrate somewhat in proximity to urban areas. Other facilities supporting boating and non-boating activities include urban or rural riverfront parks, riverfront hotel/restaurant complexes, and casino boat/resort complexes.

A number of demographic and economic factors unrelated to river navigation improvements contribute to the past and ongoing growth of recreation activities. However, virtually all the 'recreation infrastructure' discussed above has been built in relation to and is dependent upon continued maintenance of the existing system of navigation pools. Thus this class of activities at least partially meets the 'but for' criteria.

The embayments in which marinas and related facilities concentrate are a very limited resource within the Ohio River floodplain. Additionally, dredging activity within these embayments is generally required to maintain accessibility to the marinas. The expected continued growth of marinas and dredging of embayments will likely compete with or displace other resource values of the embayments, including riparian wetland and aquatic fishery habitats. Focused resource protection initiatives will likely be required to protect, maintain or restore these resource values.

C.11.3.5 Park/Forest Development and Operations

The ridges and slopes adjacent to the Ohio River floodplain are primarily forested. Most of this forestland is privately owned, but portions of Wayne, Hoosier and Shawnee national forests and some state forest lands are included. By contrast, most of the

bottomland hardwoods and/or forested wetlands of the floodplain have been converted to other land uses. Other than Ohio River Islands NWR (river miles 0 to 400) few public resource agencies have significant holdings in floodplain areas. The importance of protecting and restoring some of these resources is addressed in documentation for the ORMSS Ecosystem Restoration Program ($USACE_b$).

If protection levels approaching the goals of the Ecosystem Restoration Program are to be achieved, numerous public resource agencies, private conservation organizations and participating private landowners will need to be involved and significant public funding sources will be required. Potential participating entities include national forest and wildlife refuges; state parks, forests, wildlife refuges, wildlife management areas and nature preserves; local/regional parks, trailways and nature preserves; and properties managed by private conservation organizations.

C.11.3.6 Industrial Development

Industrial development within the floodplain is expected to continue to grow in proportion to general economic/population expansion within the broader Ohio Valley region. Many industries in the Ohio River Basin are to some degree dependent on the existence of an efficient and reliable navigation system. This includes industries that may never have shipped via barge and have no plans for doing so. In fact, some of the most highly dependent industries on waterway transportation do not ship on the rivers, but depend on the cost-savings that it provides to their suppliers, making them both more competitive. The waterway transportation system allows for lower transportation costs, and therefore lower delivered costs of basic raw materials; most importantly coal, stone, ores and chemicals, to secondary producers of goods such as electricity, coke, specialty chemicals, and construction materials. In turn, these industries generally induce demand for tertiary producers of items like steel coils and slabs, aluminum, and paper products, which are then used in factories that produce final consumer goods such as automobiles, appliances, utensils, packaging, and food products ($USACE_{a2}$, April 2000).

C.11.3.7 Brownfields Redevelopment

The availability of funding support for redevelopment of brownfields and other former hazardous waste sites is contributing to reutilization of some of these formerly abandoned sites. Limited availability of undeveloped land within some areas of the floodplain further reinforces the reuse of formerly developed sites. These abandoned or underutilized sites represent an important portion of historic urban/commercial development patterns and are an important component of many redevelopment programs. Successful redevelopment of such sites may contribute to reduced land use change impacts associated with general industrial development in the vicinity of brownfields.

C.11.3.8 Agriculture and Silviculture

Agriculture and forest products constitute the largest land use activities (by area) within or adjacent to the Ohio River floodplain. Agriculture is the dominant land use throughout most of the floodplain. Most future conversions of land use will occur on land currently in agricultural use. Privately owned forest is the primary land use on slopes and ridges adjacent to the floodplain and is relatively less threatened by land use conversions.

Forested slopes adjacent to growing metropolitan areas are subject to low-density residential development.

C.11.3.9 Transportation

Highways and railroads constitute a significant land use pattern throughout the Ohio River floodplain. In some portions of the upper river, roads and track are in place along both banks. However, transportation infrastructure throughout most of the floodplain appears to be built close to feasible capacity. Very little new construction of track seems likely for the foreseeable future and road construction will most likely be confined to widening/upgrading of existing routes rather than new construction within the floodplain.

C.11.4 Natural Disasters

Original settlement patterns along the Ohio River were directly influenced by flood patterns and indirectly influenced by periodic events such as severe storms or drought. Completion of the lock and dam navigation system, in conjunction with levees and floodwalls on the main stem and flood control reservoirs throughout the watershed, has significantly reduced the impact of flooding events. Additionally, the 100 and 500-year floodplains are fairly well defined along the main stem. Future land use patterns outside these known flood zones are unlikely to be significantly influenced by natural disasters.

C.11.5 Regulatory Environment

As discussed previously in the section on laws, regulations, ordinances, and programs; historic and contemporary land use patterns have developed with little or no influence from regulatory factors. While direct regulatory control of future development appears unlikely, a number of program areas could have some indirect influence. Brownfields programs (discussed previously) may help to focus developments on previously abandoned or underutilized sites. Other forms of publicly subsidized infrastructure development such as bridges, highways and commercial river ports can also influence future patterns.

From an opposite perspective, programs such as wetlands mitigation banking, farmland preservation, or ecosystem restoration can influence land use patterns by protecting portions of the landscape from some types of development. However, these activities would need significant expansion from current funding levels to produce significant impacts within the Ohio River corridor.

NLCD LAND COVER CLASS DEFINITIONS
[Appearance in Land Use Appendix, FIGURES C-1-11]

Land uses shown on NLCD Land Cover maps:

Water - All areas of open water or permanent ice/snow cover.

- Blue - *Open Water* - all areas of open water, generally with less than 25% cover of vegetation/land cover. *[Ohio River, other streams, lakes]*
- *Perennial Ice/Snow* - all areas characterized by year-long surface cover of ice and/or snow. *[None]*

Developed - Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc).

- Light Pink - *Low Intensity Residential* - Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.
- Red - *High Intensity Residential* - Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to100 percent of the cover.
- Red or Orange - *Commercial/Industrial/Transportation* - Includes infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential.

Barren - Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.

- *Bare Rock/Sand/Clay* - Perennially barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, beaches, and other accumulations of earthen material. *[None]*
- Dark Purple - *Quarries/Strip Mines/Gravel Pits* - Areas of extractive mining activities with significant surface expression.
- Gray - *Transitional* - Areas of sparse vegetative cover (less than 25 percent of cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clearcuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.).

Forested Upland - Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25-100 percent of the cover.

- Light Green - *Deciduous Forest* - Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.
- *Evergreen Forest* - Areas dominated by trees where 75 percent or more of the tree species `maintain their leaves all year. Canopy is never without green foliage. *[None]*
- Dark Green - *Mixed Forest* - Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.

Shrubland - Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

- *Shrubland* - Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms (e.g. herbaceous or tree) is less than 25 percent and shrubs cover exceeds the cover of the other life forms. *[None]*

Non-natural Woody - Areas dominated by non-natural woody vegetation; non-natural woody vegetative canopy accounts for 25-100 percent of the cover. The non-natural woody classification is subject to the availability of sufficient ancillary data to differentiate non-natural woody vegetation from natural woody vegetation.

- *Orchards/Vineyards/Other* - Orchards, vineyards, and other areas planted or maintained for the production of fruits, nuts, berries, or ornamentals. *[None]*

Herbaceous Upland - Upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.

- *Grasslands/Herbaceous* - Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing. *[None]*

Planted/Cultivated - Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.

- Yellow - *Pasture/Hay* - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.
- Brown - *Row Crops* - Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.

- Brown - *Small Grains* - Areas used for the production of graminoid crops such as wheat, barley, oats, and rice.
- None or Yellow - Areas used for the production of crops that do not exhibit visable vegetation as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage.
- None or Yellow - *Urban/Recreational Grasses* - Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.

Wetlands - Areas where the soil or substrate is periodically saturated with or covered with water as defined by Cowardin et al.

- Light Blue - *Woody Wetlands* - Areas where forest or shrubland vegetation accounts for 25-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.
- *Emergent Herbaceous Wetlands* - Areas where perennial herbaceous vegetation accounts for 75-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water. *[None]*

C.12 REFERENCES

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe, 1979. Classification of Wetlands and Deepwater Habitat of the United States, Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C.

Similarities and differences between Anderson and NLCD systems are as follows:

Urban or built-up classes: Commercial, Industrial, Transportation, and Communications/Utilities (all separate Anderson Level II classes) were treated as one NLCD class (Commercial/Industrial/Transportation). No attempt was made to derive Anderson Level III classes in NLCD. "Recreational" grasses, such as those that occur in golf courses or parks (treated as an urban class by Anderson) are considered to be a non-urban class in NLCD (a subdivision of "Herbaceous Planted/Cultivated). Residential (an Anderson Level II class) was divided into Low and High Intensity classes in NLCD.
Water: Anderson Level II Water classes (Streams/Canals, Lakes/Ponds, Reservoirs, Bays, Open Marine) were classed as a single class (Open Water) in NLCD.
Agriculture: Agricultural areas that are herbaceous in nature (Cropland and Pasture; Anderson Level II) are subdivided into four NLCD classes: Pasture/Hay, Row Crops, Small Grains and Fallow.
Rangeland: No rangeland class (Anderson Level I) is identified by NLCD. Rather, "rangeland" is subdivided by NLCD into Grasslands/Herbaceous and Shrubland classes.
Forest land: Evergreen Forest, Deciduous Forest and Mixed Forest are the same in both Anderson and NLCD. Clearcut and burned areas are classed as "Transitional Bare" areas in NLCD.
Wetlands: Two classes are defined by NLCD. These are Woody wetlands and Emergent/Herbaceous wetlands. These are very analogous to the Anderson Level II wetland classes.

Bare: Three NLCD classes are recognized. These are: Bare Rock/Sand Clay, Quarries/Strip Mines/Gravel Pits and Transitional Bare. These represent a consolidation of Anderson Level II classes.
Tundra: While "tundra" is treated as a distinct Anderson Level I class, tundra (including arctic/alpine vegetation) is considered to be either "Grasslands/Herbaceous" or "Shrubland" classes by NLCD.

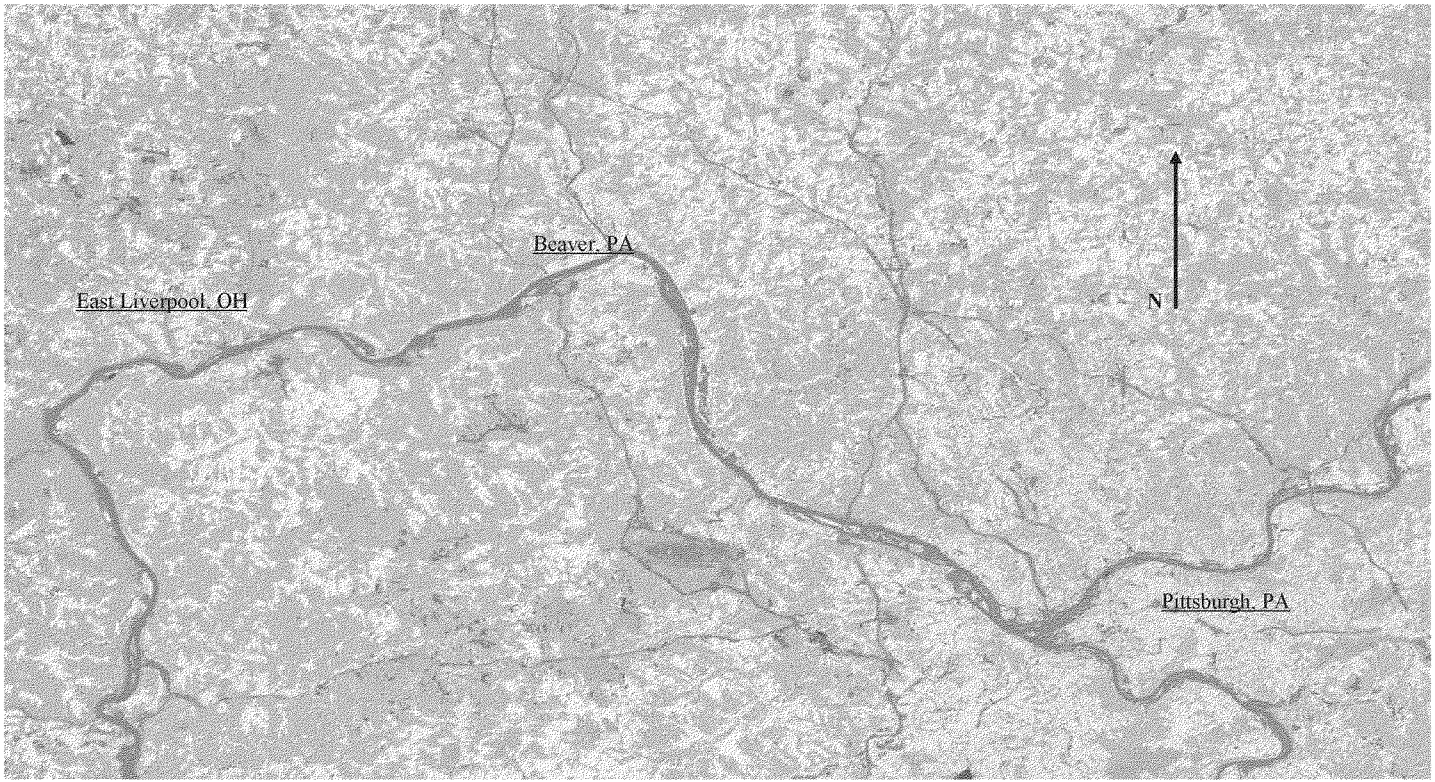


FIGURE C-1
Ohio River at Pittsburgh, PA
Source: USGS – The National Map http://seamless.usgs.gov/

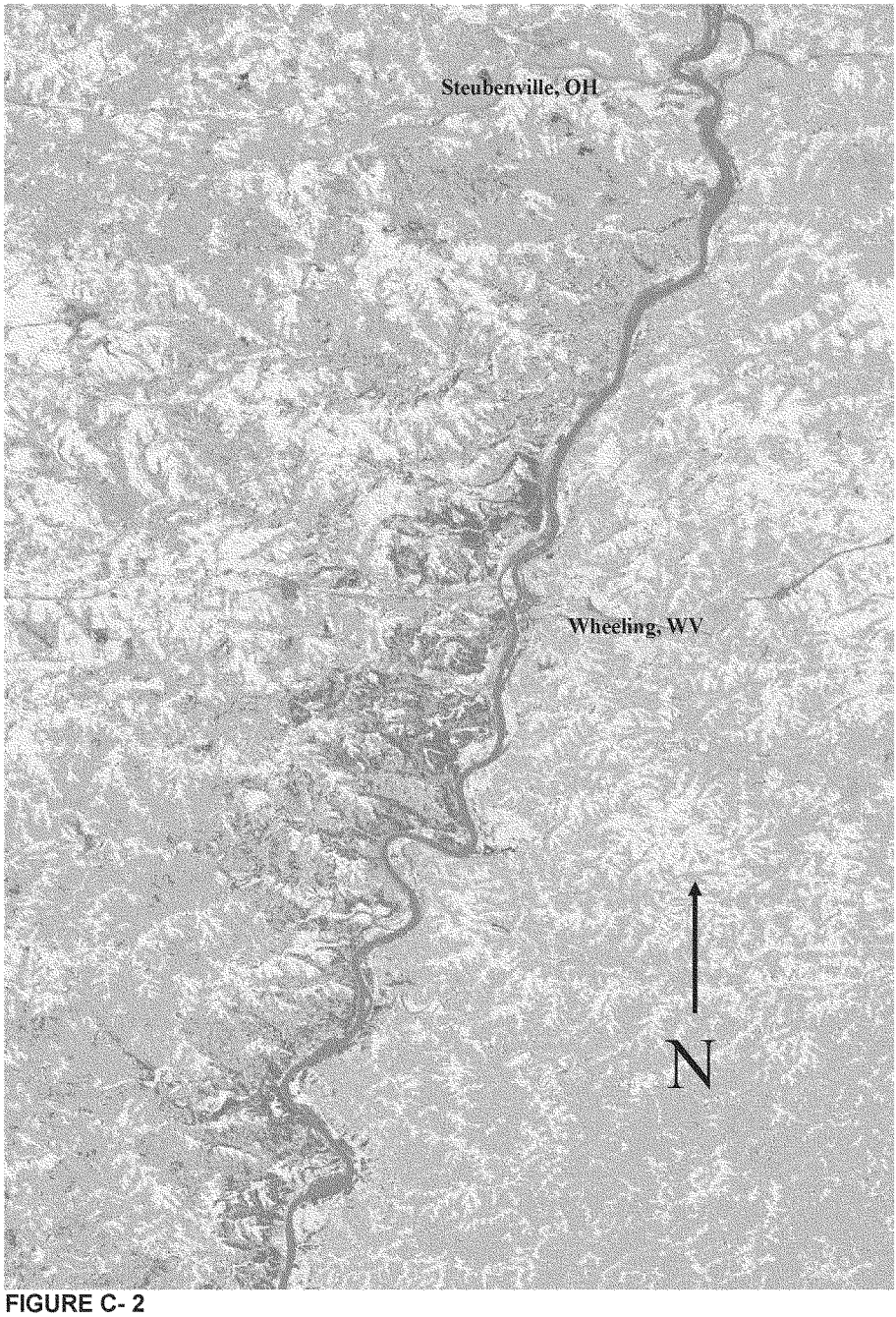


FIGURE C- 2
Ohio River, Wheeling, WV to Steubenville, OH
Source: USGS – The National Map http://seamless.usgs.gov/

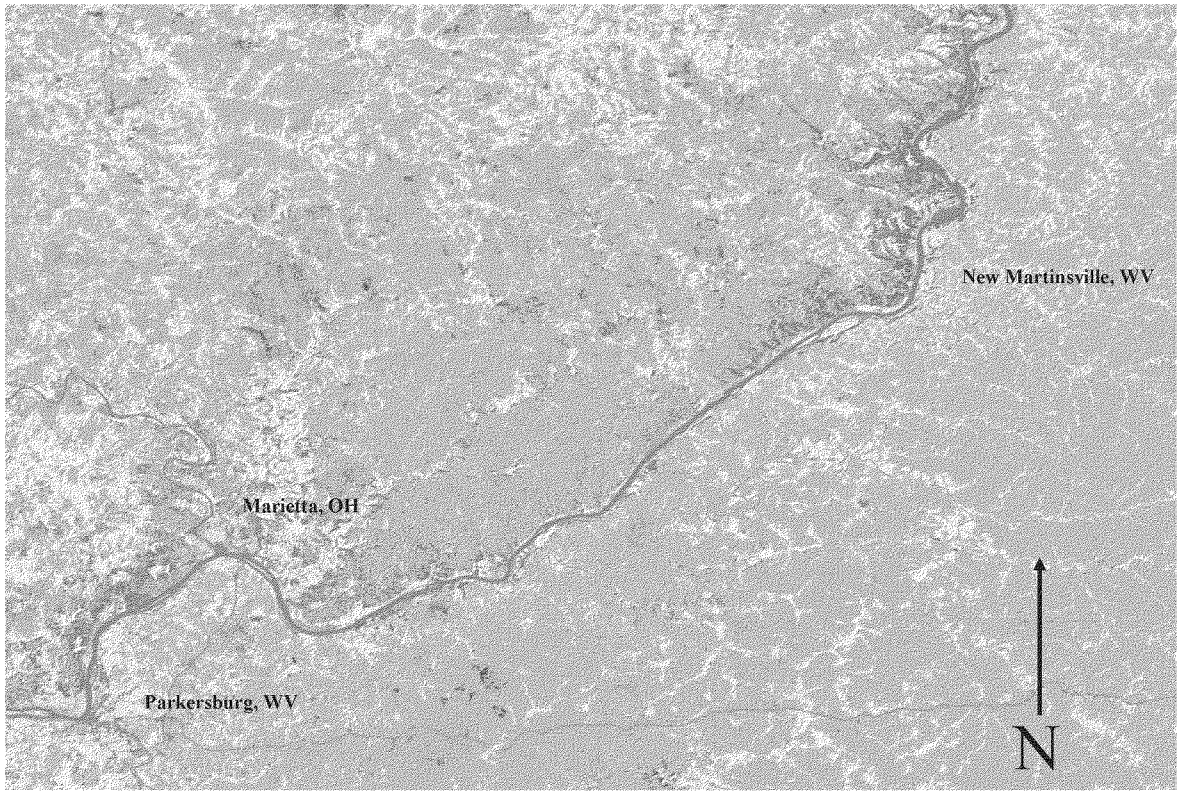


FIGURE C-3
Ohio River, Parkersburg to New Martinsville, WV
Source: USGS – The National Map http://seamless.usgs.gov/

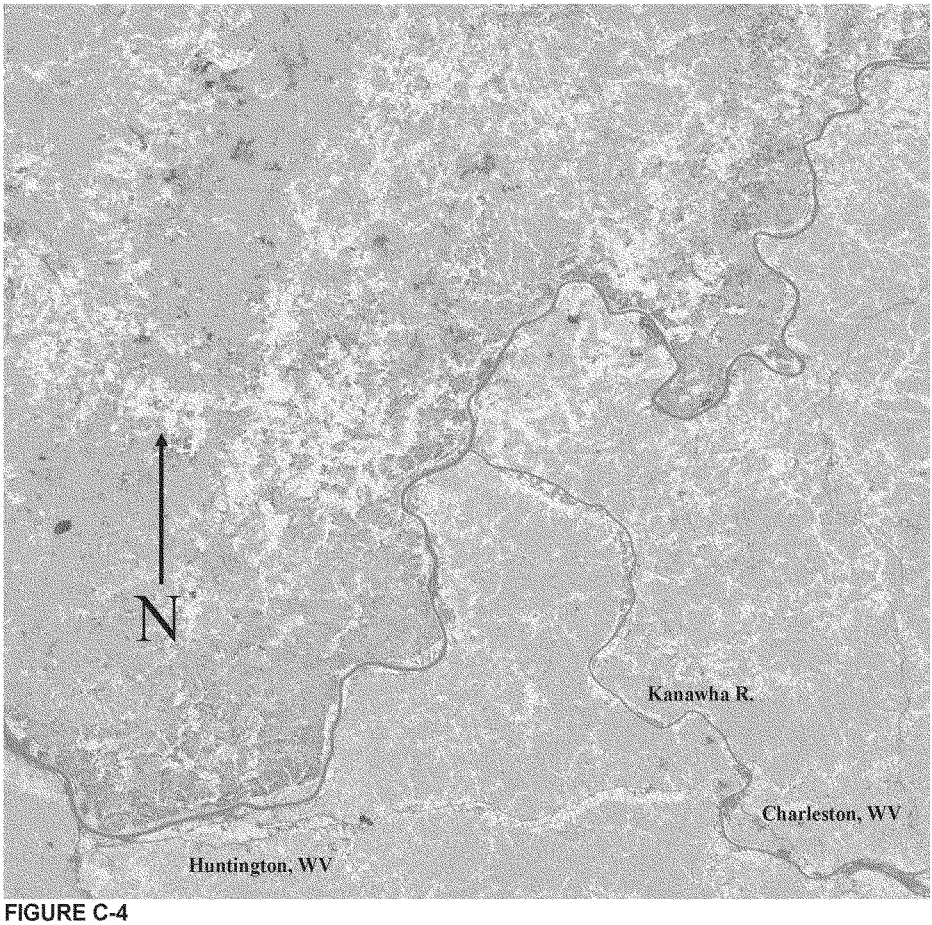


FIGURE C-4
Ohio River, Huntington to Parkersburg, WV
Source: USGS – The National Map http://seamless.usgs.gov/

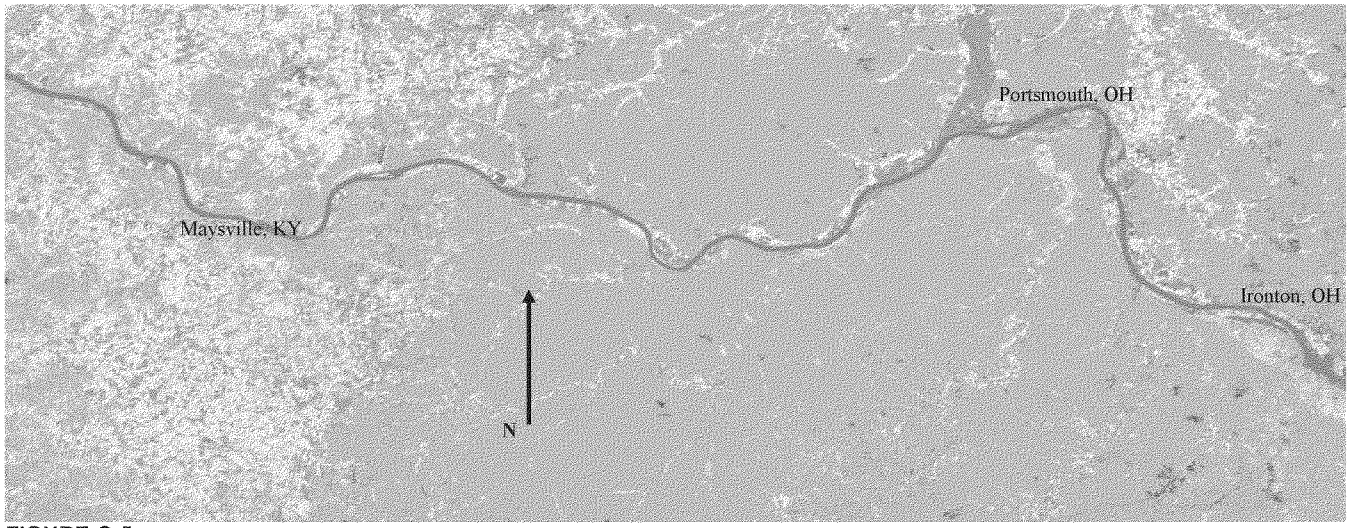


FIGURE C-5
Ohio River, Maysville to Ashland, KY
Source: USGS – The National Map http://seamless.usgs.gov/

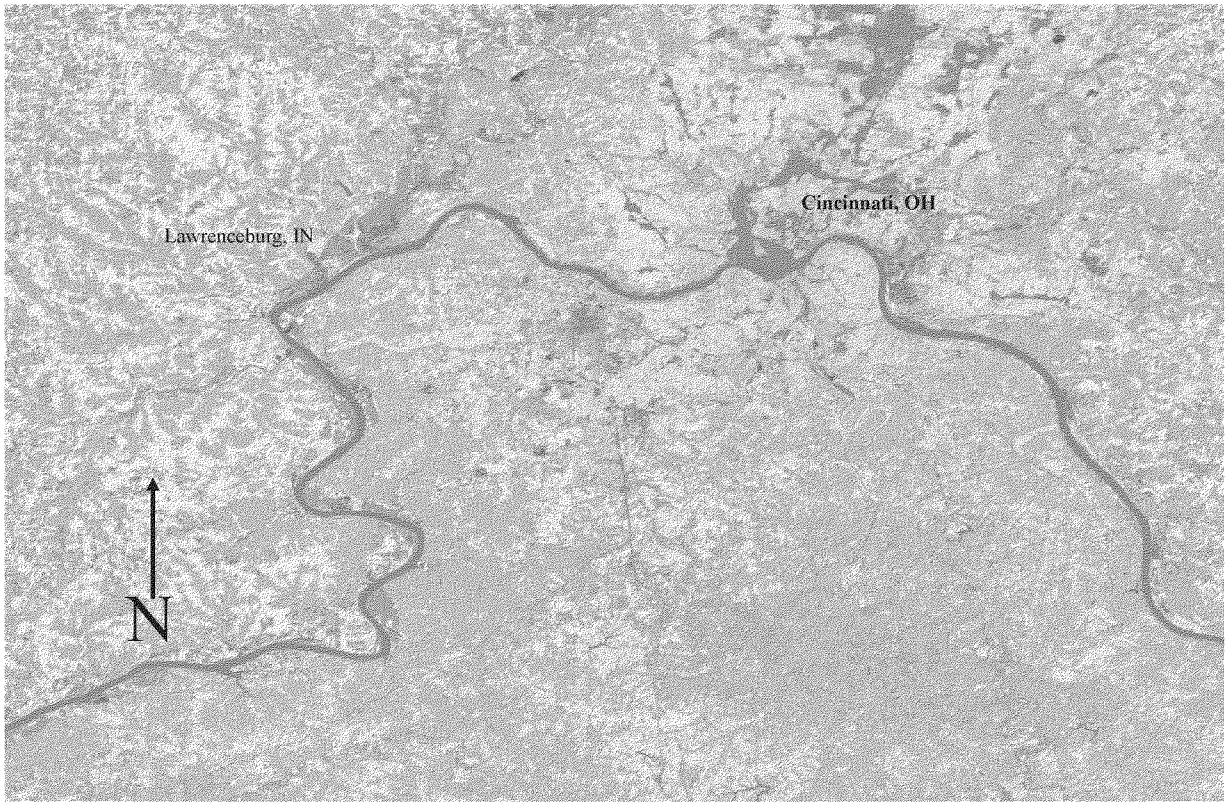


FIGURE C-6
Ohio River at Cincinnati, OH
Source: USGS – The National Map http://seamless.usgs.gov/

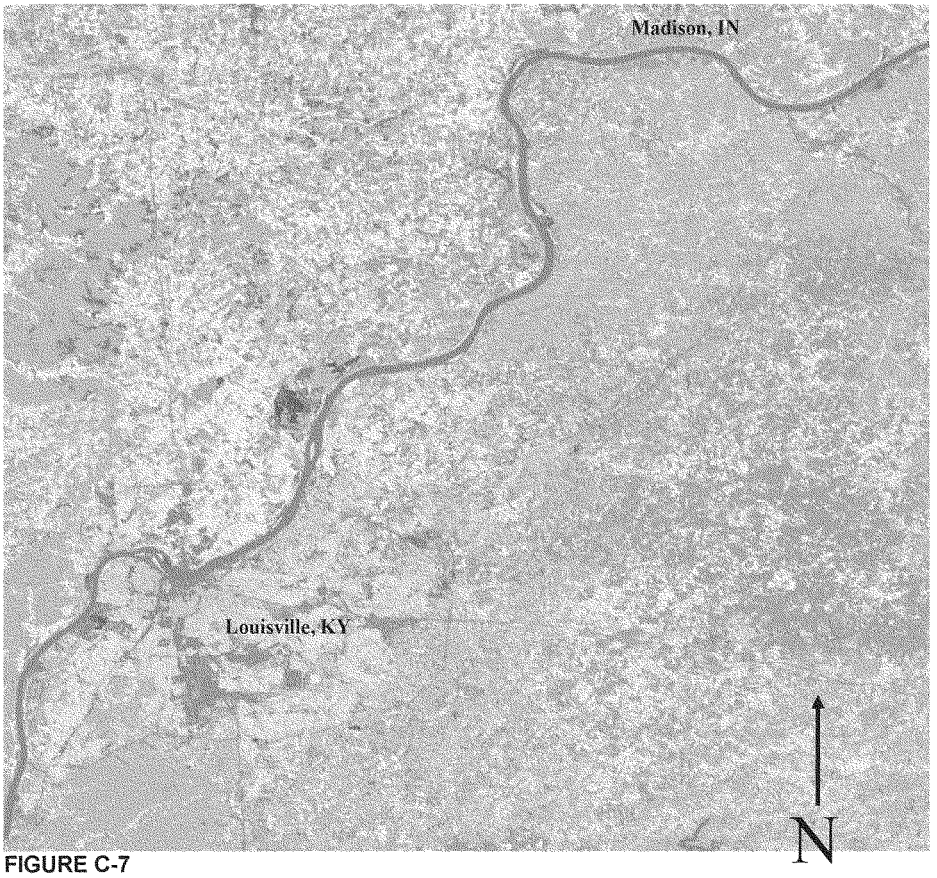


FIGURE C-7
Ohio River at Louisville, KY
Source: USGS – The National Map http://seamless.usgs.gov/

FIGURE C-8
Ohio River at Ft Knox and Louisville, KY
Source: USGS – The National Map http://seamless.usgs.gov/

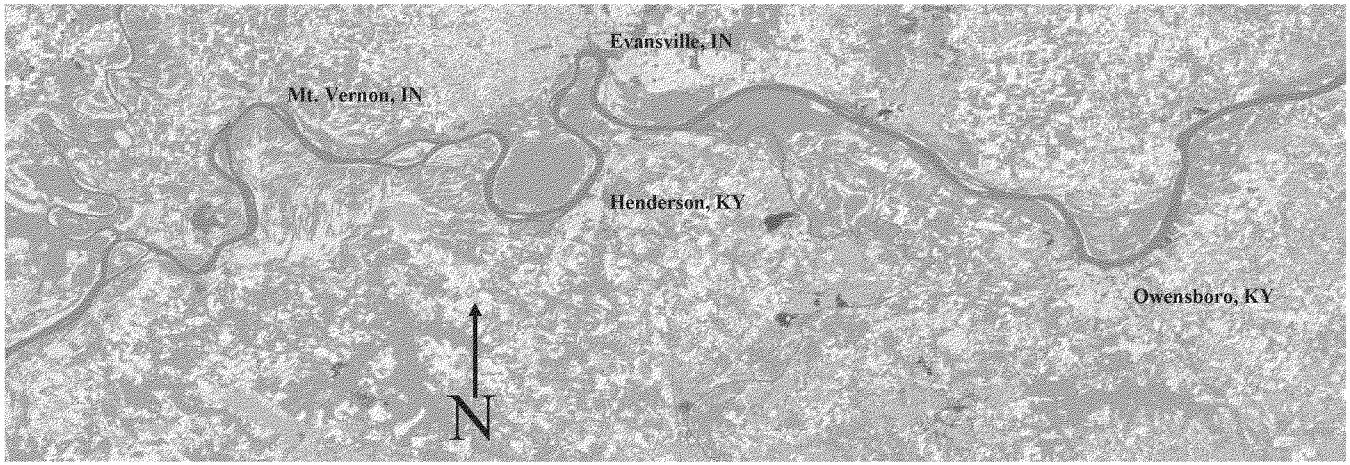


FIGURE C-9
Ohio River at Evansville, IN and Owensboro, KY
Source: USGS – The National Map http://seamless.usgs.gov/

FIGURE C-10
Ohio River at Confluence with Wabash River and Mt. Vernon, IN
Source: USGS –The National Map http://seamless.usgs.gov/

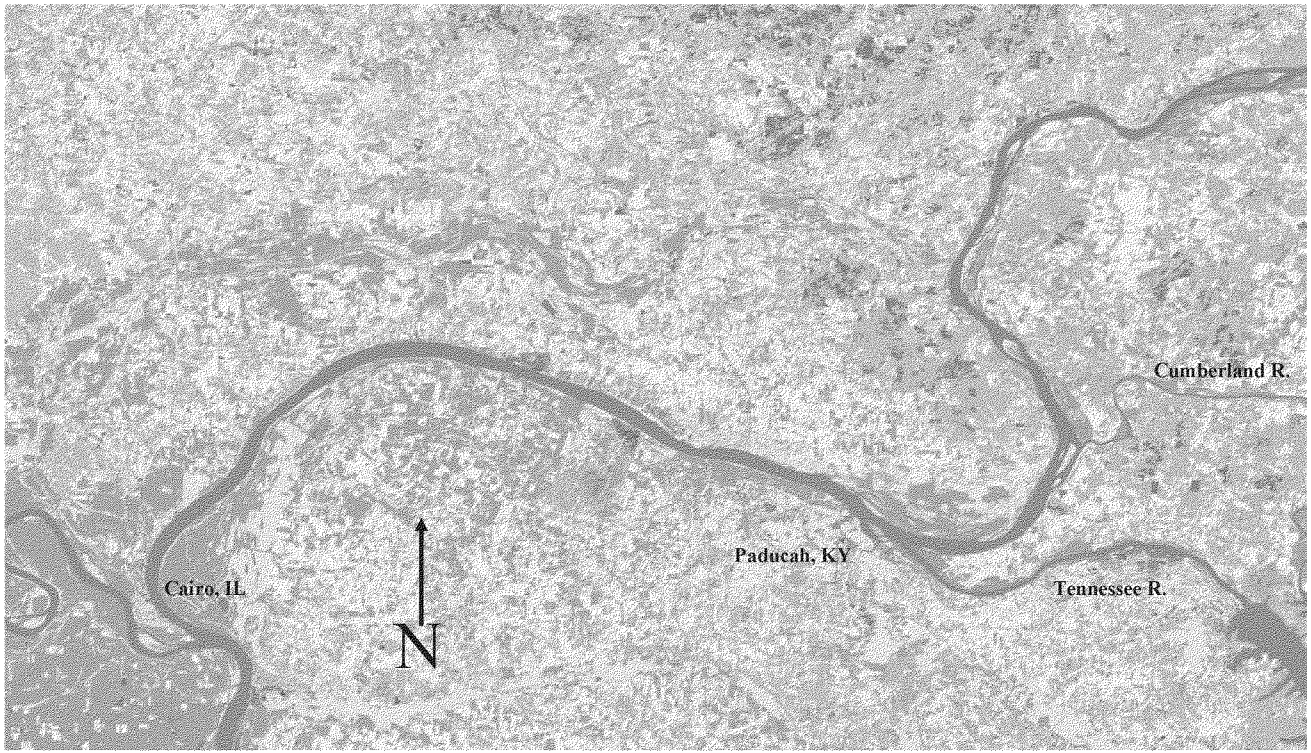


FIGURE C-11
Ohio River at Confluence with Mississippi River and Paducah, KY
Source: USGS – The National Map http://seamless.usgs.gov/

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1) Document MR Main Report & EIS
2) Document EC Economics Appendix
3) Document EC Attachment 3 – ORS Traffic Demand Forecast
4) Document ED-2 Greenup L&D Engineering Site Appendix

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US Army Corps
of Engineers
Great Lakes and Ohio River Division
LOUISVILLE DISTRICT / HUNTINGTON DISTRICT / PITTSBURGH DISTRICT

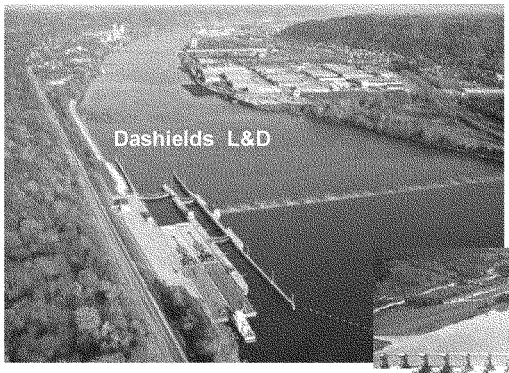
Ohio River Mainstem Systems Study (ORMSS)

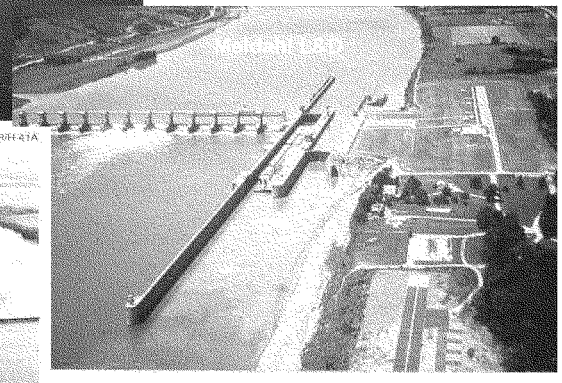
System Investment Plan/Programmatic Environmental Impact Statement

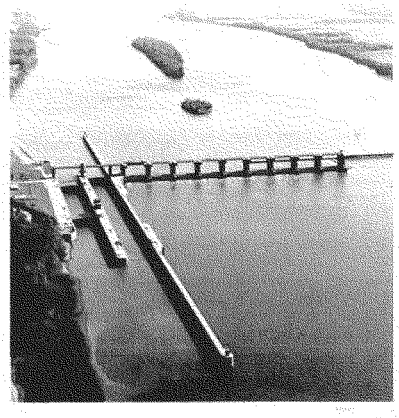
ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

ENVIRONMENTAL APPENDIX: Volume 2 of 2
NAVPAT Report
Aquatic Studies
Fish and Wildlife Coordination Act Report
Cultural Resources

COMMUNICATIONS APPENDIX







May 2006

DEPARTMENT OF THE ARMY
U.S. ARMY ENGINEER DISTRICT, LOUISVILLE
CORPS OF ENGINEERS
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System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

Environmental Appendix (Vol. 2 of 2):

NAVPAT Report
Aquatic Studies
Fish and Wildlife Coordination Act Report
Cultural Resources

Communications Appendix

May 2006

NAVPAT APPLICATION TO THE OHIO RIVER MAINSTEM SYSTEMS STUDY AND THE EVALUATION OF NAVPAT HABITAT RELATIONSHIPS

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I. Introduction

The Corps of Engineers has conducted substantial research on the effects of commercial navigation on habitats in large river systems of the United States, including the Mississippi, Ohio, and Illinois rivers. The primary goal of this research has been to assess the potential for commercial tows to disturb bottom substrates and interfere with fish reproduction, recruitment, and feeding. To address these concerns and further assess potential incremental biological effects of various navigation planning scenarios, more than 20 years ago the Louisville District of the Corps began to develop the Navigation Predictive Analysis Technique (NAVPAT). During the 1990s, the Louisville District and the US Army Engineers Research and Development Center (ERDC) developed the physical force relationships described in NAVPAT and described to some extent in Maynord (1990). Since its inception, many refinements have been made to the NAVPAT model in efforts to yield the most useful and accurate information.

The goal of NAVPAT is to provide quantitative results, which can assess positive or negative effects of tow movement on available aquatic habitat quality for a river reach or a specific area of a river cross-section (called a "cell"). Although NAVPAT focuses on certain fish species having a total of 15 species/life stages, NAVPAT does not provide specifics on the response of any particular species. Instead NAVPAT generally links tow movements to possible habitat effects. The habitat relationships in NAVPAT were developed by an interdisciplinary team from state and federal resource agencies. The original NAVPAT model is documented in USACE (1995), which states that NAVPAT "provides quantitative values of projected environmental effects of various navigation proposals at one or more time intervals in units that are habitat-based and are essentially 'habitat units'. The model was developed to assess individual tow movement on specific cells or points in a river cross-section. NAVPAT was also developed as an overall summary for multiple river reaches for numerous tow passages." The Fish and Wildlife Coordination Act report (December 1993), prepared by the U.S. Fish & Wildlife Service for the Marmet Lock project (Kanawha River, WV) states that NAVPAT should not be used as a "predictor of absolute impacts, but rather as a planning level tool" to rank navigation project alternatives.

The developers of NAVPAT emphasize that it is a useful tool for evaluating traffic-induced impacts, but NAVPAT should not be extrapolated to other human activities on or in the river. It remains unclear whether verification of NAVPAT results could be made by long-term monitoring, primarily because of the potential cumulative impacts of other human activities that could be difficult to distinguish from impacts of commercial navigation traffic.

Bearing in mind NAVPAT's purpose and limitations, the current study was designed to quantify the potential for effects on fish habitat of the Ohio River, under two different project conditions (termed "With Project" and "Without Project"), and under five different traffic scenarios that are related to national air quality policy. A secondary objective of this study was to present NAVPAT cell information in a GIS format for ease of use not only by the Corps of Engineers, but also by other agencies and river users.

Section II of this report presents additional details about NAVPAT, including information on selected fish species and their life stages. It also discusses the project conditions and traffic scenarios mentioned in the previous paragraph. In Section III, data input files are described for cross sections, traffic, tow position frequency, river stage, discharge and flow windows. Section IV addresses the methodology used in this study and provides details concerning data collection, creation of input files, analytical constraints, and analysis and interpretation. Results are presented in Section V and discussed in Section VI. Finally, recommendations (Section VII) are made for future NAVPAT modifications and applications. References, and detailed figures and tables are found in the final sections.

II. NAVPAT Description

The basis for a primary input component of NAVPAT was the selection of fish life-stages representative of fish guilds of all major habitats and life stages occurring in the large inland river systems for which NAVPAT was designed. In consultation with the USFWS, the Louisville District selected 15 life stages representing seven species which utilize a variety of large river habitats. **Table 1** presents these life stages, the identifying number each stage is assigned in NAVPAT, the rationale for species selection, and potential impacts of concern.

Table 1
Fish Life Stages Selected for Ohio River NAVPAT Model

Fish Species	Life Stages of Concern (NAVPAT number)	Rationale for Species Selection	Potential Impacts of Concern
Emerald shiner	Spawning (1) Fry (2)	Represents open water spawners in areas of lower ambient current velocity and fry with very limited mobility to avoid tow traffic	1) Dislodgment from bottom substrates of nonadhesive eggs as water velocity increases with tow passage 2) Destruction of fry caused by entrainment through propellers or associated pressure and turbulence
Paddlefish	Spawning (3) Larval stage (4)	Represents open water spawners in areas of moderate ambient current velocity and fry with very limited mobility to avoid tow traffic	1) Dislodgment from bottom substrates of adhesive eggs as water velocity increases with tow passage 2) Destruction of fry caused by entrainment through propellers or associated pressure and turbulence
Freshwater drum	Adult food (5)	Represents open water spawners in	1) Destruction of egg/larval stages caused by entrainment through

Fish Species	Life Stages of Concern (NAVPAT number)	Rationale for Species Selection	Potential Impacts of Concern
	Egg/larval stages (6)	almost any portion of a river and adults that feed on organisms found in bottom sediments	propellers or associated pressure and turbulence 2) Dislodgment of substrates caused by water velocity from tow passage
Sauger	Spawning (7) Larval stage (8)	Represent spawners in relatively high ambient current in areas with coarse substrate and larvae that move to areas of lower ambient current velocity with very limited mobility to avoid tow traffic	1) Dislodgment from bottom substrates of adhesive eggs as water velocity increases with tow passage and/or abrasion of eggs due to substrate scouring 2) Destruction of larvae caused by entrainment through propellers or associated pressure and turbulence
Channel catfish	Young-of-year (9)	Represents species whose young feed primarily on aquatic insects in shallow water with low ambient current velocity	Dislodgment of substrate caused by water velocity from tow passage which could reduce the availability of aquatic insects on which these fish feed
Black crappie	Spawning (10) Fry food (11) Juvenile food (12) Adult food (13)	Represents nest spawners in shallow water and fry, juveniles, and adults that feed significantly on benthic aquatic insects in predominantly different portions of a river channel throughout their lives	1) Dislodgment of eggs from nests because of water velocity increases with tow passage and vulnerability of eggs to predation 2) Disturbance of substrate that could deposit on eggs and smother them 3) Disturbance of substrate that could reduce the availability of aquatic insects on which these fish feed
Spotted bass	Spawning (14) Juvenile food (15)	Represents nest spawners in moderate depth water with coarse substrates and juveniles that feed significantly on small benthic invertebrates	1) Dislodgment of eggs from nests because of water velocity increases with tow passage and vulnerability of eggs to predation 2) Disturbance of substrate that could reduce the availability of aquatic insects on which these fish feed

SOURCE: U.S. Army Corps of Engineers, Environmental Effects of Commercial Navigation Traffic – McAlpine Lock and Dam Project, NAVPAT and QUEPAT (not dated).

The three other primary NAVPAT inputs are:

- river reach characteristics – including information describing multiple reaches of a river which share basic aquatic habitat conditions; i.e., reaches with similar bathymetry, substrate, depth, and velocity profiles
- economic scenarios – including data on various navigation forecasts, as well as data simulating various tows by length, width, speed, travel direction, horsepower, propeller dimensions, and other measurable characteristics, and
- physical forces – including information about several types of hydraulic forces generated by tows moving through a waterway. NAVPAT is best used in primary navigation channels as flows in side channels are significantly more complex and not with in the scope of the present model.

NAVPAT input describes the waterway by cross sections, breaks each cross section into cells having common habitat, and computes a Suitability Index (SI) for each cell for conditions with and without commercial barge traffic. The SI, developed by an interagency team of biologists and engineers, describes habitat quality and varies from 0 (no habitat value) to 1.0 (optimum habitat value). Without traffic habitat quality is determined by habitat relationships that depend on one or more of the following variables:

1) cell depth
2) cell ambient water velocity
3) cell substrate size
4) cell structure (including sunken trees, rocks, old lock walls, wrecked vessels, and other features that provide fish refuge)

Impacts considered in NAVPAT that are induced by tow traffic include:

- propeller entrainment mortality – affecting fish species with pelagic (floating) eggs/larvae in the main channel and channel border (e.g., emerald shiner, paddlefish, freshwater drum eggs/larvae)
- substrate scour – affecting demersal (deposited near the bottom) eggs/larvae in the channel border (e.g., sauger, channel catfish)
- waves/shoreline dewatering – littoral (shallow) or slackwater nest building species (e.g., sunfishes)
- vessel passage events – disrupts feeding efficiency or food availability

The SI recovers between tow events for the substrate scour and velocity effects, but does not recover between tows for propeller entrainment. The duration of the NAVPAT simulation can be important for the propeller entrainment species. NAVPAT evaluates the effects of every tow on habitat quality during the simulation period but does not address cumulative impacts on populations, communities, or trophic dynamics. The SI can be expressed either as bottom area in acres or as volume habitat units in acre-feet. Analyses and conclusions in this report are based on bottom area in acres of habitat units.

The NAVPAT model evaluates six sources of tow-induced velocity that can negatively impact fish habitat: 1) bow wave, 2) displacement flow, 3) return flow, 4) propeller jet, 5) wake flow, and 6) wave-induced velocity in shallow shoreline cells. Wave velocities are calculated only if the minimum depth in a cell is less than or equal to 2.0 ft. Each of the six components is evaluated over a 300-second time history. If two or more velocity sources are occurring simultaneously, their velocities are added together and stored as a 300-second time history of tow-induced velocity from all sources. The time history from these initial steps is then used to compute the depth to which the substrate is disturbed in the cell. A subsequent model step deals with habitat quality and calculates the without traffic SI and the effects of tows on SI. Other tasks important for NAVPAT to run smoothly include random selection of which zone in the channel will be used for simulation, computation of the percentage of the channel that is undisturbed by propeller entrainment, and computation of the percentage of a cell entrained in the propeller jet.

The NAVPAT traffic scenarios are based on five detailed lock-level traffic demand forecasts the Corps has developed for the Ohio River through use of the Ohio River Navigation Investment Model (ORNIM). These are utility coal-based forecasts that reflect the effects of coal source switching by electric utilities to comply with existing or proposed environmental regulations. The five traffic scenarios are:

1) The Bush Administration's Clear Skies Initiative, an amendment to the Clean Air Act – could be expected to have a marked impact on the use of coal by electric utilities, largely because of the proposal's implied mercury emissions restrictions.

2) The Modified Clear Skies Initiative without the severe mercury restrictions included under Clear Skies.

3) The National Ambient Air Quality Standards (NAAQS) Scenario – continues to apply existing air quality policy.

4) The Utility-Based Scenario – uses utility survey information and the Ohio River System (ORS) utility coal model to generate a forecast that reflects the utilities' view of the environmental regulatory future over the next 10 years and extrapolates trends based on projected economic growth.

5) The Utility-Based High Scenario – same as the Utility-Based except that it assumes higher economic growth.

III. Description of Input Files

III. a. Cross Sections

The cross section data files for the Ohio River mainstem were originally organized for an older version of the NAVPAT model. For ORMSS the decision was made to analyze the data with an updated version of NAVPAT, as described in the ERDC technical report TR-05-7 "NAVPAT Application to Winfield Pool, Kanawha River, and Evaluation of NAVPAT Habitat Relationships". Consequently, it was necessary to reformat the cross section data to be compatible with the updated NAVPAT. A programmer was hired to create a software application to automate the reformatting process, which substantially increased the speed at which the conversion was completed.

In addition to data reformatting, several inconsistencies, requiring manual fixes, were discovered in the cross section data and needed to be addressed before the input files could be used. For example, data for a number of pools was organized in reverse order, with the cross sections located at the furthest point upstream placed first and subsequent cross sections recorded in descending order. The order of these files had to be reversed by hand prior to running NAVPAT. In a few cases, the number of cells or bathymetry lines conveyed in the data input did not coincide with the actual number present in the bathymetry profile; or left and right cell limits were not correct. Such errors were found either by randomly scanning the cross section data or when the NAVPAT program could not successfully run. Once errors were found, changes made to NAVPAT computer source codes corrected the data files.

In many analyses of individual cells, values representing the principal substrate size were assigned a value of zero. This presented a problem for those species models requiring analysis of substrate scour (species 5, 7, 9-13, and 15, see text **Table 1**) and was adjusted, accordingly.

Many cross sections, especially in the Belleville and Willow Island Pools, included data that described multiple river channels. Although NAVPAT will run data that include more than one channel, resulting output is only valid for cross sections with a single channel. The problem required the removal of any non-navigable side channels from the cross section files. This was accomplished by raising the elevations describing a non-navigable channel above the maximum water surface elevation. Because NAVPAT does not compute results for cells with elevation values greater than the maximum water surface elevation, no changes were needed for the cells located within a side channel.

Navigation channel location data were often inaccurate and did not reflect the depth or structure of the river channel. Questionable output data is created when the NAVPAT model is asked to examine tows traveling through sections of river too shallow to accommodate barge drafts or even through areas above water level. Most cross sections were compared to navigation charts and then navigation channel data were corrected to allow adequate depth to accommodate the minimum river stage and the maximum draft tow.

A final problem with the cross section data involved points at the terminus of a profile closest to the river banks which did not extend above the maximum water surface elevation. This condition resulted in an error message and termination of the model run.

A separate program (NAVPAT_add_endpts) was written that inserted a point at the maximum water surface elevation. The lateral distance for the new point was based on a 1V:2H slope from an existing point located closest to the river bank.

III. b. Traffic Files

The strength of the NAVPAT model is its flexibility to assess changes in habitat at a variety of scales, from a single stretch of river to numerous pools. Regardless of the size of each section, the NAVPAT model requires the creation of a unique set of batch and input files. The traffic data provided by the Navigation Center was organized in such a way that each cross section was assigned a different traffic level for each of the five forecasts for each of the three years analyzed. Due to the sheer size of the ORMSS project (thousands of cross sections) and time and staffing constraints, running individual cross sections was unrealistic. Instead the data were organized into larger segments.

Although a natural method to divide the Ohio River is by pools, several pools in the mainstem do not have a consistent level of tow traffic from one end to the other. To retain such within-pool variations in tow traffic, the 18 pools were divided into 44 sub-pools. The limits of each sub-pool were established so that each cross section within the unit did not deviate by more than 2.5 million tons (+/-) from the average annual traffic level of the entire unit. To further simplify the run, the units were divided so the same sub-pools could be used on all five forecasts. The sub-pools were then run at the average tow traffic level. The output data from the sub-pools were combined to create one single value representing habitat change for each pool. This method eliminated extreme high and low levels of tow traffic predicted for each pool, but was thought to be the best compromise between limiting the number of model runs and capturing traffic variations in each pool.

The original output from the ORNIM model also had to be adjusted to accommodate the format dictated by NAVPAT. For example, ORNIM described tow speed in miles per hour, whereas NAVPAT requires tow speed in feet per second. ORNIM measurements of tow draft depth (ft) originally included the draft of the tow boat while NAVPAT uses only barge drafts. These discrepancies were identified and corrected.

After corrections were made for the ORNIM model tow speeds, it was observed that tow speeds were far too high to accurately represent actual tow movement on the Ohio River. The speed function used in ORNIM model was based on Howe (1969), which has since been described as inadequate to accurately describe navigation speeds. Consequently, the speed function for the ORNIM model was modified to establish more realistic tow speeds for the NAVPAT traffic input files.

Another inconsistency with the ORNIM model was related to the propeller rotation speed. ORNIM assigned values for propeller size (in.), propeller pitch and propeller speed (RPM). One value was assigned to each category per size class regardless of the size or speed of the tow. Consequently, the assigned propeller speed value was often

inconsistent with the physical attributes of the tow. A code added to ORNIM included formulas to determine more realistic prop speed, size, and pitch.

III. c. Tow Position Frequency Files

Because all tow position frequency files had to be created for the ORMSS data, project time constraints permitted only one frequency distribution to be used. This distribution described a centered sailing line.

III. d. Discharge and Stage Files

The updated version of NAVPAT applied to ORMSS data takes the river stage and discharge data from separate files instead of from the bathymetry file. New stage and discharge files had to be created from the data supplied by the Louisville District.

In several cases, river miles in the stage file were the same as the river mile of the first or last cross section in the bathymetry/cell file and the NAVPAT model could not successfully run. This problem was corrected by slightly increasing or decreasing the stage file river miles to overlap the river miles in the bathymetry/cell file.

Changes to the bathymetry data were made to eliminate multiple channels, but resulted in the total discharge going through the one remaining channel becoming too large. This required a modification of the discharge file to accurately reflect the flow moving through the navigable channel. The discharge files were modified by inserting four new data lines in the discharge file: at a river mile just upstream of the side channel, a new line at the upstream end of the side channel, a new line at the downstream end of the side channel, and a new line just downstream of the side channel.

III. e. Summary of Changes to NAVPAT Program

As mentioned above, several changes were made to NAVPAT to successfully apply it to ORMSS. As the input data were analyzed and complications were encountered, checks and safeguards were added to the source codes of the model, as follows:

- The width, depth, and area of cells were checked to make sure that they were not negative values, which would result if the left cell limit was greater than the right cell limit. The original NAVPAT program would have run with the negative cell width and computed negative habitat units for such cells, resulting in a decrease in habitat units for that cross section. The program was revised to terminate the run and create an error message that identified the problem cross section.

- NAVPAT was modified to account for tows with a draft greater than 12 ft.

- A problem related to computation of substrate scour for down-bound tows with large ambient velocities was encountered and corrected.

IV. Methodology

This section describes methods used to collect NAVPAT input data and create input files. Analytical constraints and analytical methods also are described below.

IV. a. Data Collection

Substrate Data

Two methods were used to collect substrate data and were correlated with the date of data collection and location on the river. The lower river (below Meldahl) was surveyed either before or during the early stages of ORMSS. These early data collections were done for site-specific studies conducted by the Louisville District, where the NAVPAT model was originally developed. Substrate samples were collected using a petite ponar dredge with samples taken at standard distances along a cross section. The location of each grab sample was determined using a Global Positioning System (GPS) unit. Subtrate classification involved analysis of grain-size distributions after sieving.

Substrate data in the middle and upper river were collected using modern side-scan sonar (SSS) equipment, which scans a wide bottom swath using high-frequency sound waves. The unit translates signal return strength into a nearly rectilinear, pictographic representation of the scanned area which reveals the presence of submerged objects, as well as patterns of bathymetric relief and substrate character. Advanced equipment was coupled with a differentially corrected, GPS receiver to render a nearly continuous record of river bed composition with spatial accuracy acceptable for translation to a geographic information system (GIS) format.

The sonar images were used to identify substrate "polygons" based on the relationship between sonar images and an extensive series of river bottom samples collected in an upper Ohio River pool (Normandeau Associates, Inc. 1997). These polygons represent areas of similar substrate composition, which can be classified as percentages of grain sizes (e.g., 20% fine sand, 30% gravel, and 50% cobble boulder).

Bathymetry Data

Bathymetry for the Ohio River was provided in three dimensional (XYZ) format with data collected along cross sections approximately 500 ft apart along the entire length of each pool. Each cross section was described by about 150 data points. As a general rule these data correlated with the pool elevation on the day of the survey. Above that elevation, digital terrain data files at 5 ft contour intervals were used to establish bathymetry to the top of bank.

Structure Data

Shoreline conditions above the water level were documented from photographs and field notes and then used to infer the structure and vegetation in the sub-aqueous cells

adjacent to the shoreline. Structure values assigned also considered the surface area of the cell being analyzed.

IV. b. Creation of NAVPAT Input Files

Bathymetry/Cell Files

NAVPAT requires the river to be divided into a series of segments which share common physical and flow characteristics. The bathymetry input files provide data which describe the physical characteristics of the river bottom based on three data lines referred to as X1, GR, and CL.

The description of each river section begins with an X1 line which contains 12 types of data:

1) An X1 header
2) River mile of the representative cross section
3) Number of GR points, as described below
4) The left limit of the navigation channel (ft from the left bank of the river),
5) The right limit of the navigation channel (ft from the right bank of the river),
6) The pool elevation in ft.
7) Number of cells in the river segment,
8) Length of the river segment (ft), and
9-12) Two pairs of XY coordinates.

Left and right navigations channel limits are determined by several factors, including water depth, channel alignment and structures present in the channel such as bridges and locks. The current version of NAVPAT reads the pool elevation from a separate input file so this value in the bathymetry input file simply acts as a place holder. The final four numbers represent two pairs of XY coordinates. Typically, the first XY pair would represent the first point of the bathymetric profile on the left bank while the second XY pair describes a point on the opposite bank and defines the edge of the cross section. However, due to time constraints during ORMSS, accurate coordinate values were not determined and zeros were used as place holders.

Each GR (geometry of the river) line describes a single point used to describe the geometry of the channel. Typically, the point in the first GR line is located at the top of the left bank. After the GR header, the first two values represent the XY coordinates of the point. The first value (Y) is the distance the point is located from the left bank. The second number (X) is the elevation of that point.

The last type of data line in the bathymetry file is the CL (cell limits) line. Each river section is further subdivided into cells parallel to the river bank which are numbered from left to right. Cell limits help maintain constancy of substrate size and minimize depth variations throughout the cell. Each CL line describes an individual cell. The CL header is followed by the cell number, the left and right limits of the cell, principle substrate particle size, the average water velocity (for a point located in the center of the cell), percent of structure in the cell and a roughness value. The current version of

NAVPAT takes the ambient velocity from another input file so the line in the bathymetry file is a place holder. Structure values are utilized in 6 of the 15 biological models and include logs, trees, docks and other features. The roughness parameter is used to calculate ambient velocity using the Manning equation, a common equation for simulating water flows in open channels.

Traffic Files

Traffic input files are produced by the Corps' Navigation Center in Huntington, WV, from the ORNIM computer model. Traffic files describe the commercial tow traffic for a given traffic scenario for a given year. Each line of a traffic input file represents one tow and describes the specific characteristics of the tow, as follows:

1) Julian Day for the time of the tow passage
2) Size class of the tow boat. The NAVPAT model recognizes 8 different size classes based on horsepower.
3) Direction of tow movement, upbound (U) or downbound (D)
4) Empty (E) or loaded (L)
5) Total length of the tow (ft)
6) Total width of the tow (ft)
7) Physical draft of the tow, excluding the push boat (ft)
8) Tow speed relative to land (ft/sec)
9) Propeller size (in)
10) Propeller pitch (in)
11) Propeller speed (rpm)
12) Presence or absence of a Kort nozzle, which enhances tow thrust.

Sailing Lines and Tow Positions

The NAVPAT model uses navigation channel data from the bathymetry files and divides the channel into five sections of equal width. These sections represent five possible positions of a tow in the navigation channel. For each tow in the traffic input file, NAVPAT randomly selects a position from one of the five possibilities. The Tow Position Frequency files consist of frequency distributions laterally across the navigation channel for each tow size class. Larger tows are confined to the center of the channel, while the smaller tows can move more freely within the entire width of the channel.

Stage and Discharge Files

Determination of ambient velocity is made by referring to a spread sheet of river stage or discharge as a function of Julian day and river mile.

IV. c. Analytical Constraints

The NAVPAT model was originally developed to assess navigation impacts to aquatic habitat for site-specific projects. When originally developed, the model strained

the computer processing capabilities and required banks of computers to run for days at a time. The processing time for pool specific runs has been reduced greatly due to the improved speeds of today's computer. Applying the full model to analyze 19 pools, however, was determined to be infeasible given the number of cross-sections, species models, scenarios, and time period of this study. Therefore, to obtain timely results, it was necessary to place some constraints on the analysis.

To put this analysis in perspective, the following variables had to be considered: Each pool was divided into one or more segments that had similar traffic characteristics. The final number of segments used in this analysis was 44. Traffic files were generated for each year within the analysis period (2010-2070). There are 15 species models that have been developed for NAVPAT that were designed to capture the full range of fish habitat types. Fish species were selected to represent three distinct groups (Swift-water Spawning, Swift-water Larval/Fry and Slackwater). Each of these models is analyzed during discrete calendar periods referred to as flow windows. There are three to eight flow windows for each species. The number depends on the species and whether it's in the upper, middle or lower pool. Each window is ten days long. Finally, ORMSS has identified 5 different forecast scenarios based on federal clean air policies that could influence the use of coal over the study period (Utility Based High, Utility Based Medium, National Ambient Air Quality Standards, Clear Skies, and Clear Skies Modified). If all of these variables were run, the total number of output files for ORMSS would have exceeded one million.

Consequently, adjustments had to be made to reduce the computing time and number of output files without sacrificing the significance of the findings. Several adjustments were necessary because NAVPAT was designed for pool-specific studies while it was used in ORMSS to analyze the entire Ohio River mainstem. The first adjustment was to reduce the runs from all 70 forecast years to three. Due to the sensitivity of the model, the decision was made to only use the initial year (2010), the final year (2070) and an intermediate year (2040). Upon completion of the runs, if the model showed large changes in habitat values between these 30 years intervals, additional runs could be made to understand the changes in more detail.

The second adjustment was in the number of species models run. The NAVPAT study conducted for the Winfield Lock Project (USACE 2005) noted that slackwater habitats were not affected by river traffic. Further, the Winfield report found that impacts were limited to species that had a specific seasonal need within the navigation channel. Year-round foragers can move away from adverse conditions and are not generally affected. Eliminating these slackwater species/life stage models from the analysis left only eight models that showed effects.

Representative pools were selected to run all fifteen models to test the hypothesis that species/life stage models behaved similarly in the Ohio River as in the Kanawha River at Winfield. The Willow Island, McAlpine, and Smithland, pools were selected to represent the upper, middle, and lower Ohio River, respectively. If the seven species/life stage models representing slackwater habitat showed changes based on the changes in

traffic, they could be run for more of the remaining pools. Even with these adjustments, the ORMSS NAVPAT runs generated approximately 150,000 output files.

IV. d. Analysis and Interpretation

As described in Section IV.c, NAVPAT model runs were made for all five traffic scenarios. In each scenario, the With Project Condition (WPC) equilibrium traffic projections were compared to the Without Project Condition (WOPC) equilibrium traffic projections. WOPC was defined as the reactive maintenance strategy, which generally includes funding to do inspections, routine maintenance, and occasional component replacements. The WPC includes advance maintenance of lock chamber components, major rehabilitation of lock chambers (wherein individual component replacements are bundled into a single major rehabilitation), and new lock chambers at Emsworth, Dashields, and Montgomery.

NAVPAT does not address the actual response of any of the species but evaluates quality and quantity of habitat for various fleet configurations and traffic levels. The model provides quantitative values of projected environmental effects of various navigation proposals at one or more time intervals in units that are habitat-based and provide a Habitat Suitability Index (HSI). The NAVPAT model outputs are in terms of certain types of aquatic habitats which were defined from river data as described in Section III.a of this report (Cross Sections).

NAVPAT exhibits variability in results that stem primarily from flow window size (defined as the time period in Julian days for which the model is run) and traffic file variability. To reduce variability from flow window size, all flow windows were set at nine days duration. Traffic files were developed by a computer program that generates distributions of tows across the channel cross section. It is important to note that NAVPAT outputs are to be used to examine for trends and compare among alternatives to determine relative degree of impacts rather than using as absolute predictions of actual effects. Finally, because of inherent variability in the model, comparison of small differences was avoided.

For data analyses the Ohio River was divided into 44 reaches to correspond to traffic patterns used in the Ohio River Navigation Investment Model (ORNIM). The boundaries for these reaches were defined by locations where there is a substantial change from one traffic pattern to another. Lock and dam projects were always treated as a boundary between reaches. Results are presented in tabular form for each pool. For any given pool on the river, the data presentation consists of the following:

- Pool name
- Species/life stage habitat type
- Percent of the river-wide total of that species/life stage habitat available in the pool
- Traffic scenario analyzed

- Total HSI Units in the pool under the WOPC and WPC in the years projected (i.e., 2010, 2040, and 2070)
- Difference in the number of HSI Units between the WOPC and WPC
- Percent change in HSI Between WOPC and WPC

Data summaries were graphically displayed with data averaged for the upper, middle, and lower reaches of the Ohio River. For these summaries, there is one graph for each river reach and species/life stage combination. For the years 2010, 2040, and 2070, each graph shows the number of HSI units under the WOPC and WPC. Results are displayed as 1) the mean of all five traffic scenarios 2) the scenario yielding the highest, and 3) the scenario yielding the lowest number of HSI units.

Although many fewer than the possible number of NAVPAT runs were made for this report, the data are available for use in any additional evaluation that may be needed.

V. Results

The results of the NAVPAT application to the ORMSS project are displayed through a series of figures and tables presented at the end of this document, as follows:

- **Figure 1** - a baseline graph of fish habitat availability for the Upper, Middle and Lower Ohio River under Without Project conditions.

- **Table 2** - exemplifying results for an individual pool (Mehdahl Pool) under both Without Project and With Project conditions for all traffic scenarios and all fish life stages.

- **Table 3** - comparing 2010 and 2070 NAVPAT outputs for Meldahl to illustrate long-term fish habitat trends.

- **Tables 4 – 6**: consolidating data (i.e., all scenarios, years, life stages and project conditions) for the Upper, Lower and Middle Ohio River. The Upper segment extends from the Emsworth Pool at Mile 0 to the Greenup Dam at Mile 341. The Middle segment continues from the Greenup Dam to the McAlpine Dam at Mile 607 and the Lower segment continues from McAlpine Dam to the Mississippi confluence at Mile 981.

- **Figures 2 – 16**: summarizing model output for 2010 and 2070 for all traffic scenarios, life stages and both project conditions for the Upper, Lower and Middle Ohio River.

- **Figures 17 – 37**: summarizing model output for 2010 and 2070 for all traffic scenarios, life stages and both project conditions for each pool on the Ohio River.

- **Tables 7 – 27**: presenting complete NAVPAT output for each pool.

VI. Discussion

For purposes of interpretation and evaluation of the results of the Ohio River Mainstem Systems Study application of NAVPAT, it is useful to briefly review the recent application of NAVPAT to the Winfield Pool of the Kanawha River.

VI. a. Kanawa River Study

This application predicted definitive patterns of impacts to different fish habitats from changes in tow configurations and from increased commercial navigation traffic. Generally, this analysis indicated three different responses to navigation traffic that were consistent with known life history patterns of the primary fish assemblages of the Kanawha River: 1) the slackwater fish life stages, 2) the swiftwater larval-fry stages, and 3) swiftwater spawning life stages.

The slackwater group of fish species/life stages showed no effects from navigation at any of the Kanawha River traffic levels evaluated. This indicates that the slackwater fish group is least affected by passing vessels in navigation channels, probably due to their nearshore habitat preferences. This group includes adult and juvenile feeding life stages, and one species/life stage in this group (Freshwater Drum-Adult Feeding) represents a fish not normally considered to be a slackwater species. Feeding behavior in this and other groups of fishes is unlike spawning behaviors, which might be completely abandoned for a season due to tow traffic. While feeding behavior might be temporarily disturbed by tow passage, fish will re-establish feeding behavior once the tow has passed.

The swiftwater larval/fry group showed impacts from increased navigation traffic, but no difference in effects between With Project or Without Project conditions. A model assumption of 100% non-recovery mortality of swiftwater larval/fry stages caused by entrainment through propellers or associated pressure shear and turbulence, however, likely tended to inflate these predicted habitat unit reductions.

Significant negative impacts from navigation to the swiftwater spawning group of fishes in the Winfield Pool of the Kanawha River were obvious. The four swiftwater spawning species/life stages evaluated were Emerald Shiner-Spawning, Paddlefish-Spawning, Sauger-Spawning, and Spotted Bass-Spawning. The corresponding Winfield Pool percent reductions in area habitat units based on one traffic increase scenario were 12%, 11%, 20%, and 34%, respectively. NAVPAT does not use the entrainment modifier in the biological model equations for the swiftwater spawning group. Entrainment only affects the swiftwater larval/fry group. All of the swiftwater spawning group species/life stages instead have a velocity modifier, so habitat loss is due to increases in ambient water velocity. For the Sauger-Spawning species/life stage, NAVPAT also includes a substrate disturbance modifier. These modifiers (water velocity and substrate disturbance) allow for recovery between tow events. It is thought

that the channel geometry of the Kanawha River (narrow and deep) allowed traffic to increase ambient water velocity throughout the entire river cross section.

Since the Kanawha River is a tributary of the Ohio River, with similar commercial navigation traffic characteristics and fish assemblages, it would be reasonable for a NAVPAT application to the Ohio River to produce results similar to those generated for the Kanawha River. A major variable that might be attributed to differences observed between these two recent NAVPAT applications is the larger size (channel width and flow) of the Ohio River relative to the Kanawha River. Vessels using the Ohio River are generally not much larger or more powerful than vessels that navigate the Kanawha River, but the aquatic environment influenced by navigation tows is more compressed along the Kanawha River. The larger system would be better able to absorb navigation impacts with diminished tow effects to its aquatic life resources.

VI. b. Ohio River Study

A clear and consistent pattern evident in the Ohio River Mainstem Study NAVPAT output is that, under either With Project or Without Project conditions, increasing river traffic between the years 2010 and 2070 will result in a loss of habitat units for Emerald Shiner-Spawning and Fry, Paddlefish-Spawning and Larval, Freshwater Drum-Larval, Sauger-Spawning and Larval, and Spotted Bass-Spawning. These loses occur under all five traffic scenarios examined, but are notably greater under the two highest traffic prediction scenarios (Utility Based and Utility Based High). These results are not in anyway surprising since the model intrinsically generates various degrees of non-recovery propeller mortality output for these species/life stages. Except for Paddlefish-Larval, Freshwater Drum-Larval, and Sauger-Larval, these NAVPAT predicted losses of habitat units for the Ohio River will be negligible to slight. The slight to moderate losses in habitat units for Paddlefish-Larval, Freshwater Drum-Larval, and Sauger-Larval are probably balanced by the great abundance of these three types of habitats all along the river. Since they are the most common existing species/life stage habitats within the Ohio River, a modest decline in the availability of these habitats is not likely to be a factor limiting populations of paddlefish, freshwater drum, or sauger in the river.

Beyond these nearly self-evident generalizations, it is very difficult to find consistent and reliable patterns of future predicted navigation influences within the massive outputs of the Ohio River Mainstem Study NAVPAT application. As discussed previously, the failure of such patterns to emerge might be related to the large size and high flows of the Ohio River mainstem, and its ability to absorb predicted additional navigation related impacts, without significantly influencing existing fishery resources within an already highly modified ecosystem.

Some suggestive evidence that system size might be a variable contributing to the differences in Ohio River and Kanawha River NAVPAT results is that the few possibly significant differences (greater than + or – 5.0% delta) observed between With Project or Without Project conditions noted for the Ohio River model application are clustered along the upper and smaller reach of the Ohio River Navigation System. Specifically,

Emerald Shiner-Spawning habitat unit deltas of –5.9% occurred in Dashields Pool in 2010 under the Utility Based and Utility Based High traffic scenarios. Paddlefish-Larval habitat unit deltas of –5.4% occurred in Racine Pool in the same year under the same traffic scenarios, and Freshwater Drum-Larval habitat unit deltas ranging from –5.2% to –8.2% were observed all along the ten uppermost pools in the river from the pool of Emsworth Dam downstream to the pool of Byrd Dam, all again for the year 2010 under Utility Based and Utility Based High traffic scenarios. These impacts to Freshwater Drum-Larval in the upper river over short term, high traffic, and under With Project conditions may be the only non-random habitat unit deltas predicted by the model. With the exception of the Spotted Bass-Spawning species/life stage, no other significant changes were observed for any other species/life stage under any traffic scenario in either 2040 or 2070, in any pool, under either With Project or Without Project conditions. It should be remembered, that while this clustering was clearly exclusive to the upper river, it nonetheless amounted to only a modest portion of the total number of 2520 specific species /life stage events predicted by the NAVPAT model for the Ohio River, and attempts to draw conclusions from this apparent pattern, therefore, should be considered speculative at best.

The Spotted Bass-Spawning species/life stage exception referred to in the preceding paragraph consisted of a total of 35 habitat unit deltas in excess of 5.0%, 15 negative and 20 positive, very randomly distributed throughout the 2010 to 2070 study period, and occurring in a random manner within the five different commercial river traffic scenarios. Of all the NAVPAT quantified fish species/life stage habitats, spawning habitat for spotted bass is by far both the most limited and the most unevenly distributed fish habitat in the Ohio River, especially in the upper and middle reaches (83% of all of the habitat suitable for spotted bass spawning is concentrated in the lower reach of the Ohio River). The very small and rather scattered number of Spotted Bass-Spawning habitat units appears to be very susceptible to random and apparently meaningless model perturbations.

In summary, the Ohio River Mainstem Study NAVPAT application successfully quantified habitat required for various life stages of the primary fish assemblages of the Ohio River, as well as the impacts of future navigation activity scenarios to these habitats. The results of this modeling effort demonstrated that increases in navigation traffic through the year 2070 will negatively, but rather modestly, impact certain groups of fishes, especially swiftwater spawning fishes. While benefits to the fishery might accrue from improvements to navigation under With Project conditions, any such benefits are apparently too small to be measured by the NAVPAT model. In part this might be related to model sensitivity. For instance, NAVPAT programming generalized river cross-sections up to one to two miles in length and normalized traffic input files within the cross-sections. Therefore, this application was not designed to identify reduction in vessel queuing impact benefits to the aquatic resource. However, the failure of the model to demonstrate significant future impacts from navigation are most likely overwhelmingly related to the ability of the Ohio River to absorb the predicted additional navigation impacts, without significantly influencing existing fishery resources within an already highly modified ecosystem.

VII. Recommendations

VII. a. General Improvements to the NAVPAT Model

While the existing edition of the Navigation Predictive Analysis Technique (NAVPAT) provides a useful tool for assessment of the impacts of commercial navigation traffic on various fish species and life stages, a number of improvements to this model would be desirable. ERDC is now in the process of generally upgrading the NAVPAT model, and future applications of NAVPAT will probably find the new ERDC version easier to manage and execute. Also, specific nomenclature should be developed to distinguish between various editions of the model, and the version used in any application should be carefully referenced. A deficiency of both the existing version of NAVPAT and the new edition under development is that neither is able to model conditions nor predict future navigation impacts for the backchannels of river islands. These backchannel reaches are very important habitat components of river ecosystems, and expansion of the model to include this habitat type should be a consideration in future improvement of the NAVPAT model. In addition, during the course of the ORMSS and similar study efforts, such as the modeling of commercial navigation impacts on the Winfield Pool of the Kanawha River, field investigators noted extreme velocity and wave/wake effects from larger V-hulled recreational vessels. At least anecdotally, it appears that the impacts of such vessels might equal or perhaps exceed those of commercial tow traffic. Therefore, it is highly recommended that impacts of recreation traffic be incorporated into future NAVPAT model development.

VII. b. Model Recalibration

As currently calibrated, NAVPAT models navigation impacts to a representative group of fifteen fish species/life stages. These model iterations were selected by an interagency expert group to assess navigation impacts on specific reaches of the navigation system. Resource agencies should be consulted whenever NAVPAT is to be applied in a different region where other species/life stages iterations might be more appropriate. In order to effectively evaluate NAVPAT habitat relationships, the use of guilds should be emphasized to promote a community-level approach to habitat assessment. Consideration should be made of probable spatial distributions of evaluation species within the river so the model can delineate specific areas where evaluation species are most and least susceptible to navigation effects. The variables of importance are depth, velocity, velocity disturbance, substrate composition, substrate disturbance, and structure. From the results of the ORMSS and other applications of NAVPAT, it appears that slackwater species and life stages are the least impacted guilds, and selection of a focused group of main channel species and life stages would be appropriate. Spawning/rearing chronologies need to be identified, and recommendations made on appropriate months to evaluate navigation related impacts. For ORMSS follow-up studies, a recalibration to include impacts to mussels and potentially additional iterations other than fish might also be a very valuable model application.

VII. c. Definition of Significant Impacts

NAVPAT integrates impacts of multiple parameters for various scenarios and produces an output of Habitat Suitability Index (HSI) units. Review and debate by aquatic scientists will be necessary to determine what magnitude of predicted loss or gain of HSI units might amount to a minimal, moderate, or a threshold of substantial impact to the resource for any particular model iteration.

VII. d. GIS Output

In addition to navigation traffic related input, the NAVPAT model requires a tremendous input of physical habitat information. For the ORMSS application, this input includes detailed bathymetry and substrate size data collected along the entire 981-mile length of the Ohio River. Calculated velocities for each model cell under various stage/discharge conditions are also model products. A lack of such comprehensive physical habitat information has long been a critically limiting factor in the characterization and management of the Ohio River ecosystem. Availability of this physical habitat information would be an extremely valuable analysis and management tool. Unfortunately, in its present form, NAVPAT does not easily yield this physical habitat input as a manageable output product. Therefore, it is a very high priority recommendation that the model be expanded to provide physical habitat GIS output.

VIII. References

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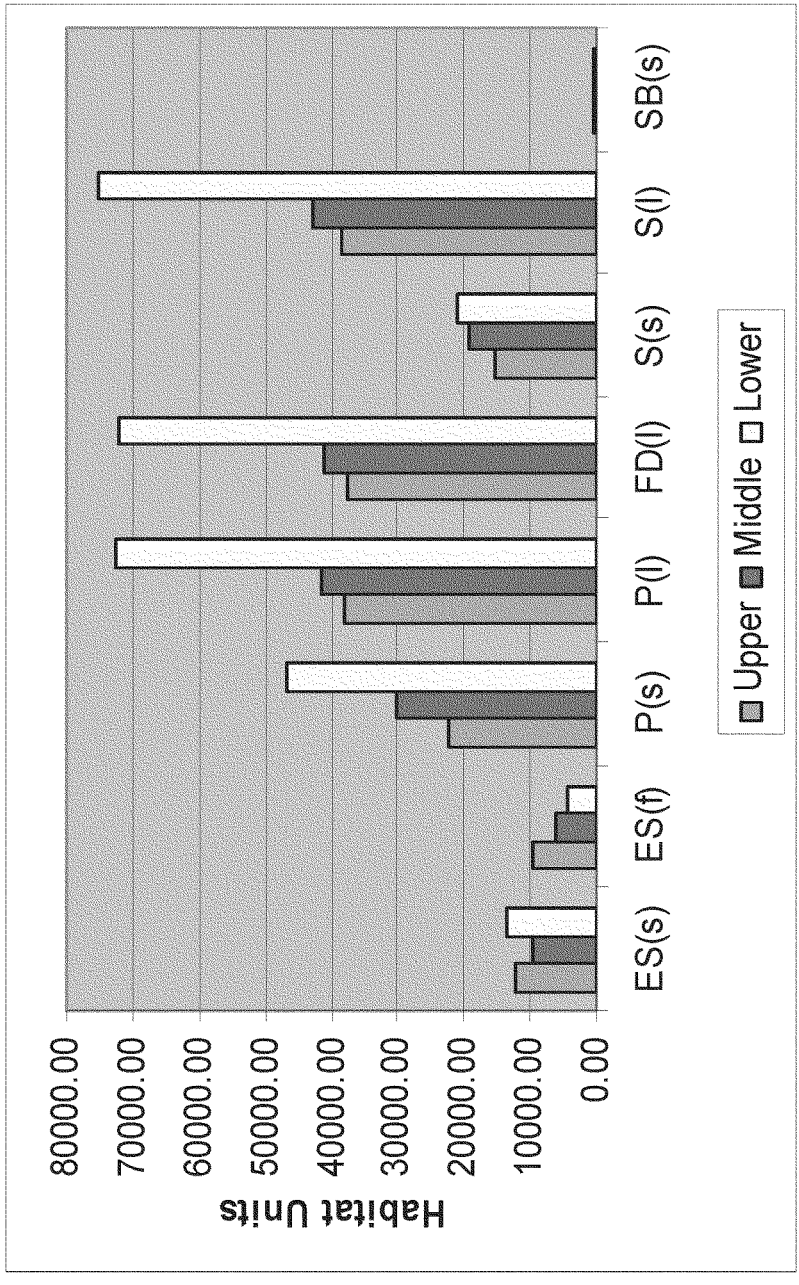
FIGURE 1
Distribution of Without Project Habitat



Note - See pages 4-5 for descriptions of fish species.

TABLE 2
NAVPAT RESULTS
MELDAHL POOL

Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070			
			Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta
ES(s)	Clear Sky w/Hg	7.6	2942.3	2939.6	2.7	0.1	2933.7	2937.8	-4.1	-0.1	2909.7	2909.3	0.4	0.0
1	Clear Sky wo/Hg	7.6	2928.7	2933.7	-5.1	-0.2	2885.5	2920.0	-34.6	-1.2	2850.9	2868.8	-17.9	-0.6
	NAAQS	7.6	2948.9	2926.7	22.2	0.8	2905.5	2918.3	-12.8	-0.4	2849.6	2878.2	-28.6	-1.0
	Utility Based (Coal)	7.6	2948.9	2888.5	60.4	2.0	2878.6	2889.6	-11.0	-0.4	2879.5	2848.3	31.2	1.1
	Utility Based High	7.6	2948.9	2888.5	60.4	2.0	2878.8	2873.8	5.0	0.2	2859.3	2878.8	-19.5	-0.7
ES(f)	Clear Sky w/Hg	8.7	1727.9	1728.3	-0.5	0.0	1717.4	1718.5	-1.1	-0.1	1706.9	1697.6	9.3	0.5
2	Clear Sky wo/Hg	8.7	1745.9	1767.6	-21.7	-1.2	1674.5	1702.3	-27.7	-1.7	1641.0	1648.5	-7.5	-0.5
	NAAQS	8.7	1727.3	1714.6	12.7	0.7	1672.5	1668.5	3.9	0.2	1652.5	1670.5	-17.9	-1.1
	Utility Based (Coal)	8.7	1703.4	1677.7	25.7	1.5	1622.6	1636.7	-14.1	-0.9	1591.7	1582.4	9.2	0.6
	Utility Based High	8.7	1703.4	1677.7	25.7	1.5	1622.4	1623.7	-1.3	-0.1	1554.9	1551.1	3.8	0.2
P(s)	Clear Sky w/Hg	9.2	9039.6	9061.4	-21.8	-0.2	9000.5	8994.6	5.9	0.1	8957.4	8963.3	-5.9	-0.1
3	Clear Sky wo/Hg	9.2	9040.4	8980.3	60.1	0.7	8984.0	8990.8	-6.8	-0.1	8899.9	8947.3	-47.5	-0.5
	NAAQS	9.2	9038.1	9081.6	-43.5	-0.5	8976.0	8938.2	37.8	0.4	8897.8	8863.2	34.6	0.4
	Utility Based (Coal)	9.2	9055.3	9046.1	9.3	0.1	8977.5	8968.3	9.3	0.1	8898.5	8883.0	15.5	0.2
	Utility Based High	9.2	9055.3	9046.1	9.3	0.1	8915.4	8893.9	21.5	0.2	8900.3	8924.7	-24.4	-0.3
P(l)	Clear Sky w/Hg	9.2	13494.4	13721.2	-226.7	-1.7	13525.3	13505.7	19.6	0.1	13057.2	12911.2	146.0	1.1
4	Clear Sky wo/Hg	9.2	13604.1	13363.5	240.6	1.8	13070.2	13055.1	15.1	0.1	12538.2	12610.8	-72.6	-0.6
	NAAQS	9.2	13595.5	13750.1	-154.6	-1.1	13253.5	13194.9	58.7	0.4	12529.2	12449.5	79.7	0.6
	Utility Based (Coal)	9.2	12734.3	12795.4	-61.1	-0.5	12163.0	12066.8	96.2	0.8	11708.3	11626.0	82.3	0.7
	Utility Based High	9.2	12734.3	12795.4	-61.1	-0.5	12016.4	12006.3	10.1	0.1	11206.1	11015.5	190.5	1.7
FD(l)	Clear Sky w/Hg	9.3	13811.6	13631.6	179.9	1.3	13574.3	13705.2	-130.9	-1.0	12930.0	13056.9	-126.9	-1.0
6	Clear Sky wo/Hg	9.3	13213.0	13639.4	-426.4	-3.2	13055.2	13059.9	-4.7	0.0	12531.2	12597.4	-66.2	-0.5
	NAAQS	9.3	13526.2	13256.3	270.0	2.0	13216.2	13275.7	-59.5	-0.5	12502.4	12708.5	-206.2	-1.6
	Utility Based (Coal)	9.3	12933.0	12554.8	378.2	2.9	12043.5	12048.0	-4.5	0.0	11421.2	11429.0	-7.8	-0.1
	Utility Based High	9.3	12933.0	12554.8	378.2	2.9	11991.4	11881.1	110.3	0.9	11269.8	10982.6	287.3	2.5
S(s)	Clear Sky w/Hg	8.5	5144.0	5129.3	14.8	0.3	5103.5	5089.7	13.9	0.3	5067.0	5045.1	21.9	0.4
7	Clear Sky wo/Hg	8.5	5069.2	5078.0	-8.8	-0.2	5077.1	5066.8	10.3	0.2	5014.4	4993.5	20.8	0.4
	NAAQS	8.5	5108.4	5153.2	-44.8	-0.9	5061.9	5056.1	5.8	0.1	5037.3	4983.7	53.6	1.1
	Utility Based (Coal)	8.5	5125.8	5140.1	-14.4	-0.3	5033.6	5034.0	-0.4	0.0	4955.3	4957.4	-2.1	0.0
	Utility Based High	8.5	5125.8	5140.1	-14.4	-0.3	4968.6	4950.1	18.4	0.4	4947.9	4931.4	16.4	0.3
S(l)	Clear Sky w/Hg	9.3	14052.0	13890.8	161.2	1.1	14027.3	14050.0	-22.7	-0.2	13365.1	13359.2	5.9	0.0
8	Clear Sky wo/Hg	9.3	13870.4	13850.1	20.3	0.1	13471.0	13405.3	65.7	0.5	12995.9	12993.5	2.5	0.0
	NAAQS	9.3	13984.6	13986.2	-1.6	0.0	13559.6	13387.3	172.3	1.3	12910.0	12887.8	22.2	0.2
	Utility Based (Coal)	9.3	13314.3	13087.2	227.1	1.7	12729.1	12553.4	175.7	1.4	11953.3	11871.8	81.5	0.7
	Utility Based High	9.3	13314.3	13087.2	227.1	1.7	12283.8	12281.8	2.0	0.0	11659.6	11642.7	16.8	0.1
SB(s)	Clear Sky w/Hg	2.3	53.9	52.4	1.4	2.7	52.8	53.5	-0.7	-1.3	53.2	53.6	-0.4	-0.8
14	Clear Sky wo/Hg	2.3	51.7	52.6	-0.8	-1.6	49.1	48.7	0.4	0.8	45.7	47.0	-1.3	-2.8
	NAAQS	2.3	50.8	50.9	-0.2	-0.4	49.2	49.4	-0.2	-0.4	46.6	48.1	-1.4	-3.1
	Utility Based (Coal)	2.3	49.2	47.6	1.6	3.3	46.4	46.6	-0.2	-0.5	43.9	43.8	0.1	0.2
	Utility Based High	2.3	49.2	47.6	1.6	3.3	45.8	46.5	-0.7	-1.5	44.2	43.4	0.8	1.8

[1]ES(s)=Emerald Shiner (spawning); ES(f)=Emerald Shiner (fry), P(s)=Paddlefish (spawning); P(l)=Paddlefish (larval); FD(l)=Freshwater Drum (larval); S(s)=Sauger (spawning), S(l)=Sauger (larval), SB(s)=Spotted Bass (spawning)

TABLE 3
NAVPAT RESULTS
MELDAHL POOL

Fish Species/ Life Stage[1]	Traffic Forecast Scenario	Without Project 2010	Without Project 2070	Delta	% Delta	With Project 2010	With Project 2070	Delta	% Delta
ES(s)	Clear Sky w/Hg	2942.27	2909.69	32.57	1.11	2939.56	2909.31	30.26	1.03
1	Clear Sky wo/Hg	2928.66	2850.90	77.75	2.65	2933.75	2868.76	64.99	2.22
	NAAQS	2948.88	2849.60	99.29	3.37	2926.68	2878.17	48.50	1.66
	Utility Based (Coal)	2948.88	2879.50	69.38	2.35	2888.45	2848.30	40.15	1.39
	Utility Based High	2948.88	2859.30	89.59	3.04	2888.45	2878.80	9.65	0.33
ES(f)	Clear Sky w/Hg	1727.86	1706.89	20.97	1.21	1728.31	1697.59	30.72	1.78
2	Clear Sky wo/Hg	1745.86	1640.97	104.89	6.01	1767.55	1648.51	119.05	6.74
	NAAQS	1727.34	1652.52	74.81	4.33	1714.59	1670.45	44.14	2.57
	Utility Based (Coal)	1703.42	1591.67	111.75	6.56	1677.70	1582.45	95.26	5.68
	Utility Based High	1703.42	1554.88	148.54	8.72	1677.70	1551.12	126.58	7.54
P(s)	Clear Sky w/Hg	9039.58	8957.40	82.18	0.91	9061.41	8963.29	98.12	1.08
3	Clear Sky wo/Hg	9040.40	8899.86	140.54	1.55	8980.29	8947.33	32.96	0.37
	NAAQS	9038.07	8897.82	140.25	1.55	9081.56	8863.17	218.39	2.40
	Utility Based (Coal)	9055.35	8898.52	156.82	1.73	9046.06	8883.02	163.05	1.80
	Utility Based High	9055.35	8900.28	155.07	1.71	9046.06	8924.67	121.40	1.34
P(l)	Clear Sky w/Hg	13494.43	13057.20	437.24	3.24	13721.17	12911.21	809.96	5.90
4	Clear Sky wo/Hg	13604.14	12538.17	1065.97	7.84	13363.53	12610.81	752.72	5.63
	NAAQS	13595.48	12529.18	1066.30	7.84	13750.10	12449.52	1300.59	9.46
	Utility Based (Coal)	12734.32	11708.32	1026.00	8.06	12795.44	11626.03	1169.41	9.14
	Utility Based High	12734.32	11206.08	1528.24	12.00	12795.44	11015.54	1779.91	13.91
FD(l)	Clear Sky w/Hg	13811.57	12930.00	881.57	6.38	13631.64	13056.90	574.74	4.22
6	Clear Sky wo/Hg	13212.96	12531.19	681.77	5.16	13639.39	12597.38	1042.01	7.64
	NAAQS	13526.22	12502.38	1023.83	7.57	13256.26	12708.54	547.73	4.13
	Utility Based (Coal)	12933.01	11421.24	1511.77	11.69	12554.77	11429.04	1125.74	8.97
	Utility Based High	12933.01	11269.82	1663.19	12.86	12554.77	10982.55	1572.22	12.52
S(s)	Clear Sky w/Hg	5144.03	5066.99	77.04	1.50	5129.27	5045.10	84.16	1.64
7	Clear Sky wo/Hg	5069.20	5014.36	54.84	1.08	5077.96	4993.53	84.43	1.66
	NAAQS	5108.42	5037.32	71.11	1.39	5153.18	4983.74	169.44	3.29
	Utility Based (Coal)	5125.78	4955.29	170.49	3.33	5140.15	4957.35	182.80	3.56
	Utility Based High	5125.78	4947.85	177.93	3.47	5140.15	4931.42	208.73	4.06
S(l)	Clear Sky w/Hg	14051.98	13365.09	686.90	4.89	13890.80	13359.23	531.57	3.83
8	Clear Sky wo/Hg	13870.40	12995.93	874.47	6.30	13850.09	12993.47	856.62	6.18
	NAAQS	13984.63	12909.96	1074.67	7.68	13986.19	12887.78	1098.41	7.85
	Utility Based (Coal)	13314.29	11953.31	1360.98	10.22	13087.17	11871.78	1215.39	9.29
	Utility Based High	13314.29	11659.56	1654.73	12.43	13087.17	11642.71	1444.46	11.04
SB(s)	Clear Sky w/Hg	53.88	53.20	0.69	1.28	52.44	53.60	-1.17	-2.23
14	Clear Sky wo/Hg	51.74	45.69	6.05	11.70	52.58	46.95	5.63	10.70
	NAAQS	50.77	46.63	4.14	8.15	50.95	48.06	2.89	5.68
	Utility Based (Coal)	49.22	43.88	5.35	10.86	47.61	43.78	3.83	8.04
	Utility Based High	49.22	44.20	5.02	10.20	47.61	43.39	4.22	8.86

TABLE 4
NAVPAT Traffic Impacts
Upper Ohio River

				2010				2040				2070				2010-2070			2010-2070		
Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Upper River	ES(s)	Clear Sky w/Hg	16980.01	12272.56	12240.45	-32.1	-0.26%	12076.2	12111.11	34.9	0.29%	11977.06	11958.25	-18.8	-0.16%	12272.56	11977.06	-2.41%	12240.45	11958.25	-2.31%
	1	Clear Sky wo/Hg	16980.01	11979.55	12076.59	97.0	0.81%	11828.6	11860.23	31.6	0.27%	11721.05	11715.82	-5.2	-0.04%	11979.55	11721.05	-2.16%	12076.59	11715.82	-2.99%
		NAAQS	16980.01	12078.60	12057.58	-21.0	-0.17%	11760.9	11784.29	23.4	0.20%	11657.51	11680.62	23.1	0.20%	12078.60	11657.51	-3.48%	12057.58	11680.62	-3.15%
		Utility Based (Coal)	16980.01	12194.56	11898.47	-296.1	-2.43%	11853.4	11888.72	35.4	0.30%	11712.96	11668.38	-44.6	-0.38%	12194.56	11712.96	-3.95%	11898.47	11668.38	-1.93%
		Utility Based High	16980.01	12194.56	11898.47	-296.1	-2.43%	11742.6	11755.55	12.9	0.11%	11619.91	11562.96	-56.9	-0.49%	12194.56	11619.91	-4.71%	11898.47	11562.96	-2.82%
	ES(f)	Clear Sky w/Hg	11559.97	9769.41	9769.73	0.3	0.00%	9441.0	9472.74	31.7	0.34%	9367.06	9342.03	-25.0	-0.27%	9769.41	9367.06	-4.12%	9769.73	9342.03	-4.36%
	2	Clear Sky wo/Hg	11559.97	9357.79	9538.40	180.6	1.93%	9269.2	9243.68	-25.5	-0.27%	8967.24	8964.67	-2.6	-0.03%	9357.79	8967.24	-4.17%	9538.40	8964.67	-6.01%
		NAAQS	11559.97	9529.03	9462.67	-66.4	-0.70%	9120.7	9105.95	-14.7	-0.16%	8933.65	8858.50	-75.2	-0.84%	9529.03	8933.65	-6.25%	9462.67	8858.50	-6.38%
		Utility Based (Coal)	11559.97	9731.31	9359.69	-371.6	-3.82%	9314.1	9350.43	36.4	0.39%	9017.18	8997.97	-19.2	-0.21%	9731.31	9017.18	-7.34%	9359.69	8997.97	-3.86%
		Utility Based High	11559.97	9731.31	9359.69	-371.6	-3.82%	9107.9	9118.18	10.3	0.11%	8876.71	8877.61	0.9	0.01%	9731.31	8876.71	-8.78%	9359.69	8877.61	-5.15%
	P(s)	Clear Sky w/Hg	28296.32	22806.87	22491.29	-315.6	-1.38%	22342.5	22283.83	-58.7	-0.26%	22344.07	22351.69	7.6	0.03%	22806.87	22344.07	-2.03%	22491.29	22351.69	-0.62%
	3	Clear Sky wo/Hg	28296.32	22119.31	22159.45	40.1	0.18%	22162.7	22066.27	-96.5	-0.44%	21869.02	22047.77	178.8	0.82%	22119.31	21869.02	-1.13%	22159.45	22047.77	-0.50%
		NAAQS	28296.32	22271.25	22383.45	112.2	0.50%	22271.2	22213.87	-57.4	-0.26%	22042.46	22026.19	-16.3	-0.07%	22271.25	22042.46	-1.03%	22383.45	22026.19	-1.60%
		Utility Based (Coal)	28296.32	22210.03	22270.08	60.0	0.27%	21954.9	22020.78	65.9	0.30%	21878.24	21833.21	-45.0	-0.21%	22210.03	21878.24	-1.49%	22270.08	21833.21	-1.96%
		Utility Based High	28296.32	22210.03	22270.08	60.0	0.27%	21910.8	21917.27	6.5	0.03%	21844.70	21738.84	-105.9	-0.48%	22210.03	21844.70	-1.64%	22270.08	21738.84	-2.39%
	P(l)	Clear Sky w/Hg	53908.67	40019.14	39609.24	-409.9	-1.02%	37932.7	37988.67	56.0	0.15%	37322.97	37502.49	179.5	0.48%	40019.14	37322.97	-6.74%	39609.24	37502.49	-5.32%
	4	Clear Sky wo/Hg	53908.67	37277.97	37984.95	707.0	1.90%	36074.7	36375.24	300.5	0.83%	35038.74	35098.77	60.0	0.17%	37277.97	35038.74	-6.01%	37984.95	35098.77	-7.60%
		NAAQS	53908.67	38035.08	37834.37	-200.7	-0.53%	36007.4	36114.31	106.9	0.30%	34766.22	34955.97	189.8	0.55%	38035.08	34766.22	-8.59%	37834.37	34955.97	-7.61%
		Utility Based (Coal)	53908.67	38925.22	37364.69	-1560.5	-4.01%	36593.4	36875.42	282.0	0.77%	35174.80	34825.12	-349.7	-0.99%	38925.22	35174.80	-9.63%	37364.69	34825.12	-6.80%
		Utility Based High	53908.67	38925.22	37364.69	-1560.5	-4.01%	35699.1	35756.37	57.2	0.16%	34099.13	33889.70	-209.4	-0.61%	38925.22	34099.13	-12.40%	37364.69	33889.70	-9.30%
	FD(l)	Clear Sky w/Hg	53768.14	39187.47	38982.95	-204.5	-0.52%	37321.5	37579.47	257.9	0.69%	36368.16	36400.04	31.9	0.09%	39187.47	36368.16	-7.19%	38982.95	36400.04	-6.63%
	6	Clear Sky wo/Hg	53768.14	36866.71	38105.86	1239.1	3.36%	35930.3	36315.65	385.3	1.07%	34111.63	33831.66	-280.0	-0.82%	36866.71	34111.63	-7.47%	38105.86	33831.66	-11.22%
		NAAQS	53768.14	37434.41	37174.71	-259.7	-0.69%	35280.3	35284.27	4.0	0.01%	33812.43	33824.93	12.5	0.04%	37434.41	33812.43	-9.68%	37174.71	33824.93	-9.01%
		Utility Based (Coal)	53768.14	38972.77	36708.83	-2263.9	-5.81%	35641.4	36275.93	634.5	1.78%	34018.50	33501.55	-517.0	-1.52%	38972.77	34018.50	-12.71%	36708.83	33501.55	-8.74%
		Utility Based High	53768.14	38972.77	36708.83	-2263.9	-5.81%	34862.9	34962.54	99.7	0.29%	32945.65	32844.08	-101.6	-0.31%	38972.77	32945.65	-15.48%	36708.83	32844.08	-10.53%
	S(s)	Clear Sky w/Hg	25427.15	15708.68	15662.91	-45.8	-0.29%	15263.3	15217.38	-45.9	-0.30%	15234.51	15183.88	-50.6	-0.33%	15708.68	15234.51	-3.02%	15662.91	15183.88	-3.06%
	7	Clear Sky wo/Hg	25427.15	14913.27	15073.02	159.7	1.07%	14995.6	14949.79	-45.8	-0.31%	14701.46	14757.59	56.1	0.38%	14913.27	14701.46	-1.42%	15073.02	14757.59	-2.09%
		NAAQS	25427.15	15292.36	15244.76	-47.6	-0.31%	14919.1	14943.34	24.3	0.16%	14930.54	14755.79	-174.7	-1.17%	15292.36	14930.54	-2.37%	15244.76	14755.79	-3.21%
		Utility Based (Coal)	25427.15	15368.98	15369.14	0.2	0.00%	14948.5	15067.31	118.8	0.79%	14830.27	14646.25	-184.0	-1.24%	15368.98	14830.27	-3.51%	15369.14	14646.25	-4.70%
		Utility Based High	25427.15	15368.98	15369.14	0.2	0.00%	14701.9	14889.04	187.2	1.27%	14706.62	14699.75	-6.9	-0.05%	15368.98	14706.62	-4.31%	15369.14	14699.75	-4.36%
	S(l)	Clear Sky w/Hg	54041.38	40626.31	39708.11	-918.2	-2.26%	39325.9	39301.92	-24.0	-0.06%	38473.62	38786.44	312.8	0.81%	40626.31	38473.62	-5.30%	39708.11	38786.44	-2.32%
	8	Clear Sky wo/Hg	54041.38	38432.39	38305.26	-127.1	-0.33%	37297.0	37150.01	-147.0	-0.39%	35648.17	35841.24	193.1	0.54%	38432.39	35648.17	-7.24%	38305.26	35841.24	-6.43%
		NAAQS	54041.38	38608.03	38844.22	236.2	0.61%	37302.5	37067.13	-235.4	-0.63%	35572.22	35495.75	-76.5	-0.21%	38608.03	35572.22	-7.88%	38844.22	35495.75	-8.62%
		Utility Based (Coal)	54041.38	38914.43	38921.29	6.9	0.02%	37819.4	37976.95	157.6	0.42%	36090.98	35870.30	-220.7	-0.61%	38914.43	36090.98	-7.26%	38921.29	35870.30	-7.84%
		Utility Based High	54041.38	38914.43	38921.29	6.9	0.02%	36912.9	37181.24	268.4	0.73%	35798.58	35118.93	-679.6	-1.90%	38914.43	35798.58	-8.01%	38921.29	35118.93	-9.77%
	SB(s)	Clear Sky w/Hg	2514.335	586.51	586.59	0.1	0.01%	528.9	531.54	2.7	0.50%	538.35	545.22	6.9	1.28%	586.51	538.35	-8.21%	586.59	545.22	-7.06%
	14	Clear Sky wo/Hg	2514.335	522.04	514.93	-7.1	-1.36%	475.3	469.22	-6.1	-1.28%	441.24	441.27	0.0	0.01%	522.04	441.24	-15.48%	514.93	441.27	-14.31%
		NAAQS	2514.335	539.86	540.45	0.6	0.11%	460.6	467.18	6.6	1.43%	441.59	436.28	-5.3	-1.20%	539.86	441.59	-18.20%	540.45	436.28	-19.27%
		Utility Based (Coal)	2514.335	572.74	554.97	-17.8	-3.10%	514.6	516.13	1.6	0.30%	478.36	469.55	-8.8	-1.84%	572.74	478.36	-16.48%	554.97	469.55	-15.39%
		Utility Based High	2514.335	572.74	554.97	-17.8	-3.10%	503.9	501.25	-2.6	-0.52%	436.93	453.34	16.4	3.76%	572.74	436.93	-23.71%	554.97	453.34	-18.31%

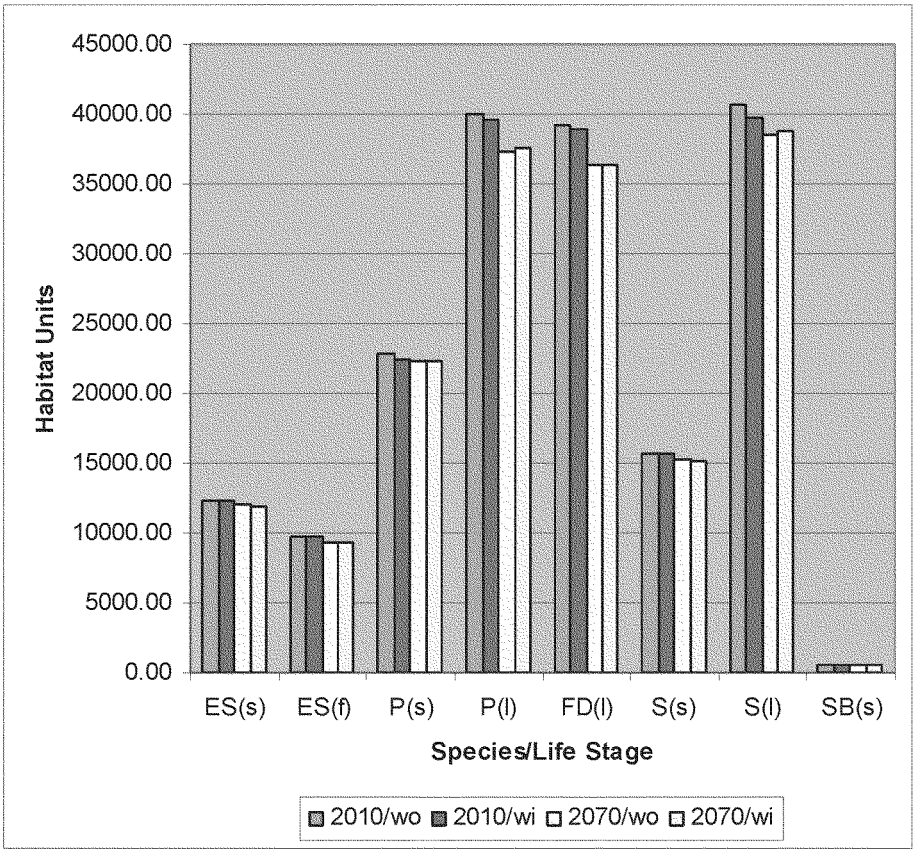
TABLE 5
NAVPAT Traffic Impacts
Middle Ohio River

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Middle River	ES(s)	Clear Sky w/Hg	11200.42	9445.39	9432.28	-13.1	-0.14%	9380.2	9404.34	24.2	0.26%	9321.78	9292.59	-29.2	-0.31%	9445.39	9321.78	-1.31%	9432.28	9292.59	-1.48%
	1	Clear Sky wo/Hg	11200.42	9408.03	9407.90	-0.1	0.00%	9278.6	9364.97	86.4	0.93%	9171.98	9196.66	24.7	0.27%	9408.03	9171.98	-2.51%	9407.90	9196.66	-2.25%
		NAAQS	11200.42	9419.25	9396.92	-22.3	-0.24%	9302.9	9342.72	39.8	0.43%	9164.65	9207.01	42.4	0.46%	9419.25	9164.65	-2.70%	9396.92	9207.01	-2.02%
		Utility Based (Coal)	11200.42	9423.80	9271.68	-152.1	-1.61%	9251.3	9253.74	2.5	0.03%	9229.99	9137.48	-92.5	-1.00%	9423.80	9229.99	-2.06%	9271.68	9137.48	-1.45%
		Utility Based High	11200.42	9423.80	9271.68	-152.1	-1.61%	9260.5	9223.90	-36.6	-0.40%	9173.47	9232.71	59.2	0.65%	9423.80	9173.47	-2.66%	9271.68	9232.71	-0.42%
	ES(f)	Clear Sky w/Hg	6667.675	5897.70	5897.65	-0.1	0.00%	5812.9	5812.00	-0.9	-0.02%	5750.76	5740.36	-10.4	-0.18%	5897.70	5750.76	-2.49%	5897.65	5740.36	-2.67%
	2	Clear Sky wo/Hg	6667.675	5882.98	5979.36	96.4	1.64%	5679.4	5796.38	117.0	2.06%	5624.24	5661.09	36.8	0.66%	5882.98	5624.24	-4.40%	5979.36	5661.09	-5.32%
		NAAQS	6667.675	5907.47	5858.14	-49.3	-0.84%	5699.1	5712.94	13.9	0.24%	5656.10	5715.37	59.3	1.05%	5907.47	5656.10	-4.26%	5858.14	5715.37	-2.44%
		Utility Based (Coal)	6667.675	5847.57	5765.88	-81.7	-1.40%	5585.6	5660.22	74.6	1.34%	5533.11	5484.33	-48.8	-0.88%	5847.57	5533.11	-5.38%	5765.88	5484.33	-4.88%
		Utility Based High	6667.675	5847.57	5765.88	-81.7	-1.40%	5611.9	5652.49	40.6	0.72%	5429.38	5488.38	59.0	1.09%	5847.57	5429.38	-7.15%	5765.88	5488.38	-4.81%
	P(s)	Clear Sky w/Hg	34629.74	30348.12	30292.82	-55.3	-0.18%	30075.8	30061.83	-13.9	-0.05%	29989.64	30022.26	32.6	0.11%	30348.12	29989.64	-1.18%	30292.82	30022.26	-0.89%
	3	Clear Sky wo/Hg	34629.74	30260.06	30164.57	-95.5	-0.32%	30139.2	30124.45	-14.8	-0.05%	29803.24	29959.62	156.4	0.52%	30260.06	29803.24	-1.51%	30164.57	29959.62	-0.68%
		NAAQS	34629.74	30300.24	30420.70	120.5	0.40%	30120.3	29989.29	-131.0	-0.44%	29884.29	29746.39	-137.9	-0.46%	30300.24	29884.29	-1.37%	30420.70	29746.39	-2.22%
		Utility Based (Coal)	34629.74	30349.91	30312.24	-37.7	-0.12%	30090.3	30134.62	44.3	0.15%	29896.55	29870.07	-26.5	-0.09%	30349.91	29896.55	-1.49%	30312.24	29870.07	-1.46%
		Utility Based High	34629.74	30349.91	30312.24	-37.7	-0.12%	30003.1	29887.75	-115.4	-0.38%	29861.22	29894.18	33.0	0.11%	30349.91	29861.22	-1.61%	30312.24	29894.18	-1.38%
	P(l)	Clear Sky w/Hg	54228.63	41590.71	42118.65	527.9	1.27%	40981.3	40949.45	-31.9	-0.08%	39686.43	39229.54	-456.9	-1.15%	41590.71	39686.43	-4.58%	42118.65	39229.54	-6.86%
	4	Clear Sky wo/Hg	54228.63	41582.14	41093.11	-489.0	-1.18%	40067.6	40181.18	113.6	0.28%	38764.39	38959.85	195.5	0.50%	41582.14	38764.39	-6.78%	41093.11	38959.85	-5.19%
		NAAQS	54228.63	41611.60	42110.21	498.6	1.20%	40731.9	40380.89	-351.0	-0.86%	38624.05	38212.16	-411.9	-1.07%	41611.60	38624.05	-7.18%	42110.21	38212.16	-9.26%
		Utility Based (Coal)	54228.63	39765.03	40143.97	378.9	0.95%	38513.3	38274.70	-238.6	-0.62%	37244.57	37233.41	-11.2	-0.03%	39765.03	37244.57	-6.34%	40143.97	37233.41	-7.25%
		Utility Based High	54228.63	39765.03	40143.97	378.9	0.95%	38054.9	38138.15	83.3	0.22%	35979.48	35607.77	-371.7	-1.03%	39765.03	35979.48	-9.52%	40143.97	35607.77	-11.30%
	FD(l)	Clear Sky w/Hg	54045.49	41942.72	42009.99	67.3	0.16%	40860.9	41248.45	387.6	0.95%	39274.06	39288.84	14.8	0.04%	41942.72	39274.06	-6.36%	42009.99	39288.84	-6.49%
	6	Clear Sky wo/Hg	54045.49	40555.75	41766.71	1211.0	2.99%	40126.9	40287.97	161.1	0.40%	38668.11	38931.99	263.9	0.68%	40555.75	38668.11	-4.65%	41766.71	38931.99	-6.79%
		NAAQS	54045.49	41300.32	41011.83	-288.5	-0.70%	40396.2	40672.78	276.6	0.68%	38378.24	38555.44	177.2	0.46%	41300.32	38378.24	-7.08%	41011.83	38555.44	-5.99%
		Utility Based (Coal)	54045.49	40330.99	39274.34	-1056.7	-2.62%	38183.7	38205.81	22.1	0.06%	36680.68	36720.24	39.6	0.11%	40330.99	36680.68	-9.05%	39274.34	36720.24	-6.50%
		Utility Based High	54045.49	40330.99	39274.34	-1056.7	-2.62%	38189.3	38095.74	-93.5	-0.24%	36305.65	35641.71	-663.9	-1.83%	40330.99	36305.65	-9.98%	39274.34	35641.71	-9.25%
	S(s)	Clear Sky w/Hg	28044.77	19292.95	19262.54	-30.4	-0.16%	19040.9	18991.37	-49.5	-0.26%	18874.55	18786.44	-88.1	-0.47%	19292.95	18874.55	-2.17%	19262.54	18786.44	-2.47%
	7	Clear Sky wo/Hg	28044.77	18977.04	19025.54	48.5	0.26%	18919.7	18800.88	-118.8	-0.63%	18704.14	18666.37	-37.8	-0.20%	18977.04	18704.14	-1.44%	19025.54	18666.37	-1.89%
		NAAQS	28044.77	19153.90	19345.47	191.6	1.00%	18947.4	18893.42	-54.0	-0.28%	18790.28	18643.51	-146.8	-0.78%	19153.90	18790.28	-1.90%	19345.47	18643.51	-3.63%
		Utility Based (Coal)	28044.77	19198.57	19254.71	56.1	0.29%	18812.2	18842.48	30.3	0.16%	18607.61	18593.61	-14.0	-0.08%	19198.57	18607.61	-3.05%	19254.71	18593.61	-3.43%
		Utility Based High	28044.77	19198.57	19254.71	56.1	0.29%	18622.6	18570.24	-52.3	-0.28%	18503.75	18510.23	6.5	0.04%	19198.57	18503.75	-3.62%	19254.71	18510.23	-3.67%
	S(l)	Clear Sky w/Hg	54492.33	43248.68	43014.87	-233.8	-0.54%	42207.2	42237.80	30.6	0.07%	40541.25	40631.77	90.5	0.22%	43248.68	40541.25	-6.26%	43014.87	40631.77	-5.54%
	8	Clear Sky wo/Hg	54492.33	42641.91	42792.98	151.1	0.35%	41348.4	41445.95	97.6	0.24%	39813.73	40096.31	282.6	0.71%	42641.91	39813.73	-6.63%	42792.98	40096.31	-6.30%
		NAAQS	54492.33	42874.43	43123.03	248.6	0.58%	41398.4	40954.83	-443.5	-1.07%	39412.16	39610.26	198.1	0.50%	42874.43	39412.16	-8.09%	43123.03	39610.26	-8.15%
		Utility Based (Coal)	54492.33	41614.14	40845.95	-768.2	-1.85%	39799.7	39474.05	-325.7	-0.82%	38100.03	37950.46	-149.6	-0.39%	41614.14	38100.03	-8.44%	40845.95	37950.46	-7.09%
		Utility Based High	54492.33	41614.14	40845.95	-768.2	-1.85%	38956.4	38990.67	34.2	0.09%	37472.09	37519.03	46.9	0.13%	41614.14	37472.09	-9.95%	40845.95	37519.03	-8.15%
	SB(s)	Clear Sky w/Hg	1020.18	294.84	296.04	1.2	0.41%	294.9	298.39	3.4	1.17%	289.72	293.77	4.1	1.40%	294.84	289.72	-1.74%	296.04	293.77	-0.77%
	14	Clear Sky wo/Hg	1020.18	294.27	299.25	5.0	1.69%	283.5	281.64	-1.9	-0.66%	266.27	273.41	7.1	2.68%	294.27	266.27	-9.51%	299.25	273.41	-8.63%
		NAAQS	1020.18	294.03	298.24	4.2	1.43%	274.9	277.56	2.6	0.96%	268.07	275.02	7.0	2.59%	294.03	268.07	-8.83%	298.24	275.02	-7.79%
		Utility Based (Coal)	1020.18	279.69	266.07	-13.6	-4.87%	266.3	272.82	6.6	2.46%	256.41	256.72	0.3	0.12%	279.69	256.41	-8.32%	266.07	256.72	-3.51%
		Utility Based High	1020.18	279.69	266.07	-13.6	-4.87%	265.2	266.50	1.3	0.49%	258.72	256.90	-1.8	-0.71%	279.69	258.72	-7.50%	266.07	256.90	-3.46%

TABLE 6
NAVPAT Traffic Impacts
Lower Ohio River

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Lower River	ES(s)	Clear Sky w/Hg	17224.82	13789.33	13811.36	22.0	0.16%	13669.6	13675.12	5.5	0.04%	13659.20	13632.06	-27.1	-0.20%	13789.33	13659.20	-0.94%	13811.36	13632.06	-1.30%
	1	Clear Sky wo/Hg	17224.82	13711.34	13704.29	-7.0	-0.05%	13619.3	13669.16	49.9	0.37%	13423.51	13532.62	109.1	0.81%	13711.34	13423.51	-2.10%	13704.29	13532.62	-1.25%
		NAAQS	17224.82	13728.88	13810.35	81.5	0.59%	13673.5	13663.62	-9.8	-0.07%	13402.17	13392.87	-9.3	-0.07%	13728.88	13402.17	-2.38%	13810.35	13392.87	-3.02%
		Utility Based (Coal)	17224.82	13704.74	13645.82	-58.9	-0.43%	13597.7	13627.68	30.0	0.22%	13494.10	13461.94	-32.2	-0.24%	13704.74	13494.10	-1.54%	13645.82	13461.94	-1.35%
		Utility Based High	17224.82	13704.74	13645.82	-58.9	-0.43%	13665.4	13682.90	17.5	0.13%	13464.79	13495.49	30.7	0.23%	13704.74	13464.79	-1.75%	13645.82	13495.49	-1.10%
	ES(f)	Clear Sky w/Hg	4445.69	4275.85	4260.41	-15.4	-0.36%	4239.0	4242.81	3.8	0.09%	4213.30	4209.83	-3.5	-0.08%	4275.85	4213.30	-1.46%	4260.41	4209.83	-1.19%
	2	Clear Sky wo/Hg	4445.69	4248.13	4264.12	16.0	0.38%	4217.5	4238.81	21.3	0.51%	4204.15	4186.58	-17.6	-0.42%	4248.13	4204.15	-1.04%	4264.12	4186.58	-1.82%
		NAAQS	4445.69	4266.73	4258.19	-8.5	-0.20%	4233.7	4249.39	15.7	0.37%	4196.21	4191.65	-4.6	-0.11%	4266.73	4196.21	-1.65%	4258.19	4191.65	-1.56%
		Utility Based (Coal)	4445.69	4241.13	4254.30	13.2	0.31%	4219.4	4210.36	-9.0	-0.21%	4200.07	4192.43	-7.6	-0.18%	4241.13	4200.07	-0.97%	4254.30	4192.43	-1.45%
		Utility Based High	4445.69	4241.13	4254.30	13.2	0.31%	4231.6	4234.98	3.4	0.08%	4200.00	4167.42	-32.6	-0.78%	4241.13	4200.00	-0.97%	4254.30	4167.42	-2.04%
	P(s)	Clear Sky w/Hg	52839.54	46966.72	46970.01	3.3	0.01%	46611.5	46621.96	10.5	0.02%	46466.77	46438.07	-28.7	-0.06%	46966.72	46466.77	-1.06%	46970.01	46438.07	-1.13%
	3	Clear Sky wo/Hg	52839.54	46796.24	46829.98	33.7	0.07%	46552.0	46600.16	48.1	0.10%	46163.38	46330.59	167.2	0.36%	46796.24	46163.38	-1.35%	46829.98	46330.59	-1.07%
		NAAQS	52839.54	46787.74	47059.89	272.2	0.58%	46522.9	46514.73	-8.2	-0.02%	46215.89	46151.66	-64.2	-0.14%	46787.74	46215.89	-1.22%	47059.89	46151.66	-1.93%
		Utility Based (Coal)	52839.54	46929.00	46886.69	-42.3	-0.09%	46614.7	46604.54	-10.1	-0.02%	46389.96	46320.73	-69.2	-0.15%	46929.00	46389.96	-1.15%	46886.69	46320.73	-1.21%
		Utility Based High	52839.54	46929.00	46886.69	-42.3	-0.09%	46551.7	46410.39	-141.3	-0.30%	46330.65	46289.99	-40.7	-0.09%	46929.00	46330.65	-1.28%	46886.69	46289.99	-1.27%
	P(l)	Clear Sky w/Hg	88704.49	72767.94	72542.39	-225.6	-0.31%	70723.4	70635.58	-87.9	-0.12%	69014.94	68984.78	-30.2	-0.04%	72767.94	69014.94	-5.16%	72542.39	68984.78	-4.90%
	4	Clear Sky wo/Hg	88704.49	72330.22	72452.03	121.8	0.17%	69855.0	70063.77	208.7	0.30%	68119.98	68622.47	502.5	0.74%	72330.22	68119.98	-5.82%	72452.03	68622.47	-5.29%
		NAAQS	88704.49	72546.06	72177.48	-368.6	-0.51%	69710.1	70394.64	684.5	0.98%	67562.65	67966.07	403.4	0.60%	72546.06	67562.65	-6.87%	72177.48	67966.07	-5.83%
		Utility Based (Coal)	88704.49	72139.04	72208.35	69.3	0.10%	69423.1	70082.96	659.9	0.95%	68395.08	67296.81	-1098.3	-1.61%	72139.04	68395.08	-5.19%	72208.35	67296.81	-6.80%
		Utility Based High	88704.49	72139.04	72208.35	69.3	0.10%	69999.0	69908.04	-90.9	-0.13%	67227.67	67770.06	542.4	0.81%	72139.04	67227.67	-6.81%	72208.35	67770.06	-6.16%
	FD(l)	Clear Sky w/Hg	88612.29	71694.64	72641.02	946.4	1.32%	70624.3	70727.51	103.3	0.15%	68743.38	68050.03	-693.3	-1.01%	71694.64	68743.38	-4.12%	72641.02	68050.03	-6.32%
	6	Clear Sky wo/Hg	88612.29	72023.30	72174.41	151.1	0.21%	70271.6	70289.80	18.2	0.03%	67538.95	69032.97	1494.0	2.21%	72023.30	67538.95	-6.23%	72174.41	69032.97	-4.35%
		NAAQS	88612.29	72043.46	72864.84	821.4	1.14%	70639.7	70373.59	-266.1	-0.38%	67950.74	68359.17	408.4	0.60%	72043.46	67950.74	-5.68%	72864.84	68359.17	-6.18%
		Utility Based (Coal)	88612.29	72818.65	72540.64	-278.0	-0.38%	70498.8	69890.31	-608.5	-0.86%	69534.96	68294.17	-1240.8	-1.78%	72818.65	69534.96	-4.51%	72540.64	68294.17	-5.86%
		Utility Based High	88612.29	72818.65	72540.64	-278.0	-0.38%	69276.4	69939.02	662.6	0.96%	68203.98	67301.66	-902.3	-1.32%	72818.65	68203.98	-6.34%	72540.64	67301.66	-7.22%
	S(s)	Clear Sky w/Hg	32092.98	21210.17	21218.70	8.5	0.04%	21141.0	21161.42	20.5	0.10%	20720.63	20753.36	32.7	0.16%	21210.17	20720.63	-2.31%	21218.70	20753.36	-2.19%
	7	Clear Sky wo/Hg	32092.98	20968.05	21103.40	135.3	0.65%	20895.0	20843.88	-51.1	-0.24%	20644.11	20688.67	44.6	0.22%	20968.05	20644.11	-1.54%	21103.40	20688.67	-1.97%
		NAAQS	32092.98	21051.79	21286.10	234.3	1.11%	20817.0	20760.92	-56.1	-0.27%	20769.90	20648.15	-121.7	-0.59%	21051.79	20769.90	-1.34%	21286.10	20648.15	-3.00%
		Utility Based (Coal)	32092.98	21107.31	21266.13	158.8	0.75%	20857.9	21079.80	221.8	1.06%	20690.78	20671.43	-19.4	-0.09%	21107.31	20690.78	-1.97%	21266.13	20671.43	-2.80%
		Utility Based High	32092.98	21107.31	21266.13	158.8	0.75%	20863.7	20934.87	71.1	0.34%	20667.05	20772.10	105.1	0.51%	21107.31	20667.05	-2.09%	21266.13	20772.10	-2.32%
	S(l)	Clear Sky w/Hg	90076.21	75394.46	75643.94	249.5	0.33%	73841.6	73748.88	-92.7	-0.13%	71976.38	72242.62	266.2	0.37%	75394.46	71976.38	-4.53%	75643.94	72242.62	-4.50%
	8	Clear Sky wo/Hg	90076.21	74897.72	75320.95	423.2	0.57%	73581.0	73369.57	-211.5	-0.29%	71300.20	72329.28	1029.1	1.44%	74897.72	71300.20	-4.80%	75320.95	72329.28	-3.97%
		NAAQS	90076.21	75373.25	76575.37	1202.1	1.59%	73314.8	73179.28	-135.5	-0.18%	70576.46	71337.94	761.5	1.08%	75373.25	70576.46	-6.36%	76575.37	71337.94	-6.84%
		Utility Based (Coal)	90076.21	75446.10	75333.55	-112.6	-0.15%	72733.4	72877.47	144.1	0.20%	71274.24	71017.74	-256.5	-0.36%	75446.10	71274.24	-5.53%	75333.55	71017.74	-5.73%
		Utility Based High	90076.21	75446.10	75333.55	-112.6	-0.15%	72749.6	72630.35	-119.3	-0.16%	71188.34	71259.64	71.3	0.10%	75446.10	71188.34	-5.64%	75333.55	71259.64	-5.41%
	SB(s)	Clear Sky w/Hg	1016.283	286.85	295.43	8.6	2.99%	293.5	292.56	-0.9	-0.31%	278.76	274.75	-4.0	-1.44%	286.85	278.76	-2.82%	295.43	274.75	-7.00%
	14	Clear Sky wo/Hg	1016.283	289.43	279.64	-9.8	-3.38%	281.7	286.22	4.5	1.59%	267.60	271.78	4.2	1.56%	289.43	267.60	-7.54%	279.64	271.78	-2.81%
		NAAQS	1016.283	287.40	290.33	2.9	1.02%	277.9	274.74	-3.2	-1.15%	263.89	277.06	13.2	4.99%	287.40	263.89	-8.18%	290.33	277.06	-4.57%
		Utility Based (Coal)	1016.283	296.70	287.71	-9.0	-3.03%	281.2	270.73	-10.5	-3.73%	273.56	271.28	-2.3	-0.84%	296.70	273.56	-7.80%	287.71	271.28	-5.71%
		Utility Based High	1016.283	296.70	287.71	-9.0	-3.03%	269.5	269.79	0.3	0.11%	266.13	268.08	1.9	0.73%	296.70	266.13	-10.30%	287.71	268.08	-6.82%

FIGURE 2
Clear Skies w/Hg - Upper River



Species/Life Stage: ES(s)=Emerald Shiner (spawning); ES(f)= Emerald Shiner (fry); P(s)=Paddlefish (spawning); P(l)= Paddlefish (larval); FD(l)=Freshwater Drum (larval); S(s)=Sauger (spawning); S(l)= Sauger (larval); SB(s)=Spotted Bass (spawning)

FIGURE 3
Clear Skies w/o Hg - Upper River

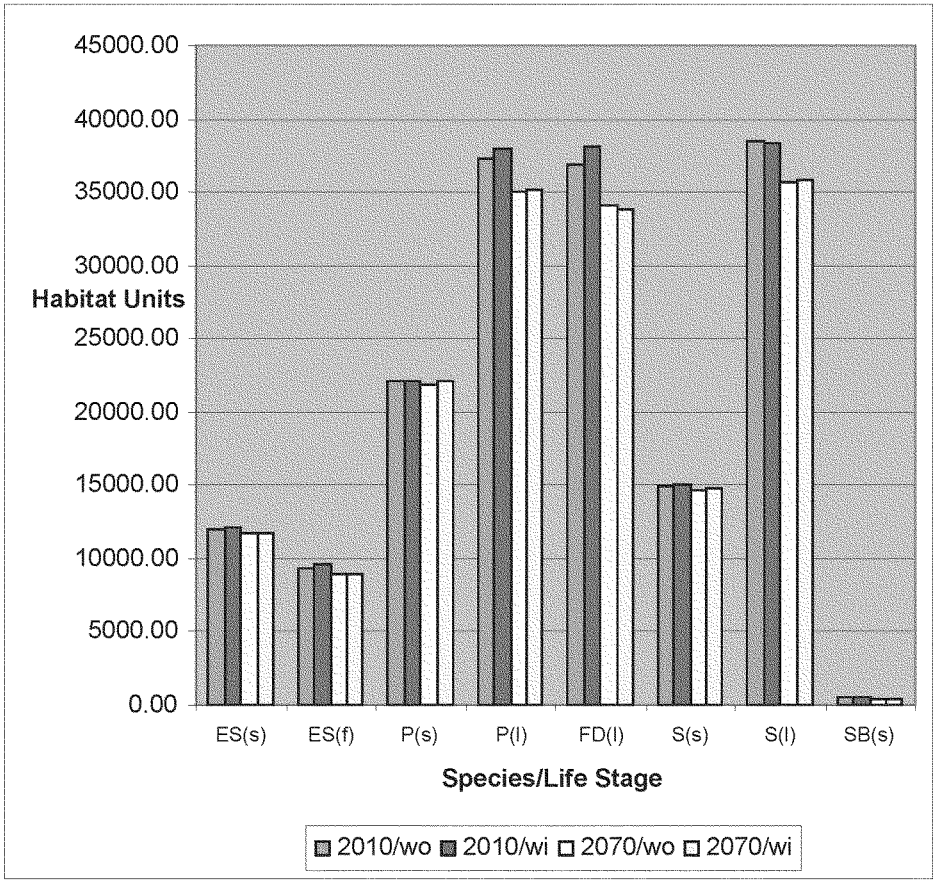


FIGURE 4
NAAQS- Upper River

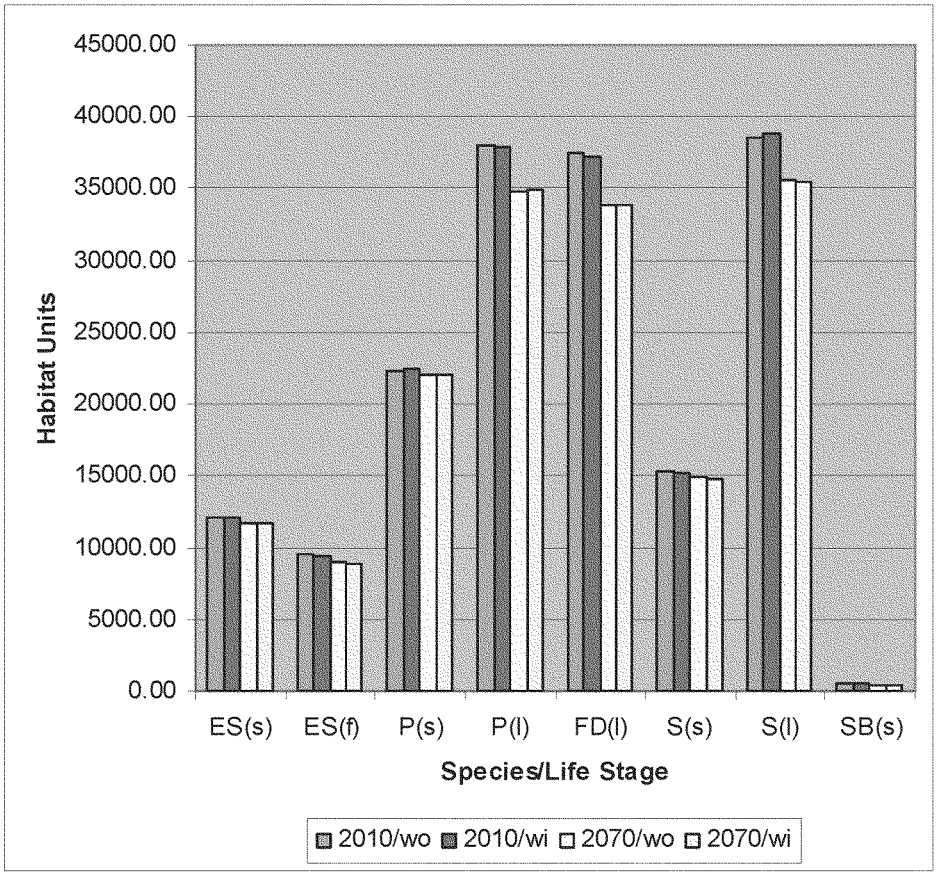


FIGURE 5
Utility Based (coal) - Upper River

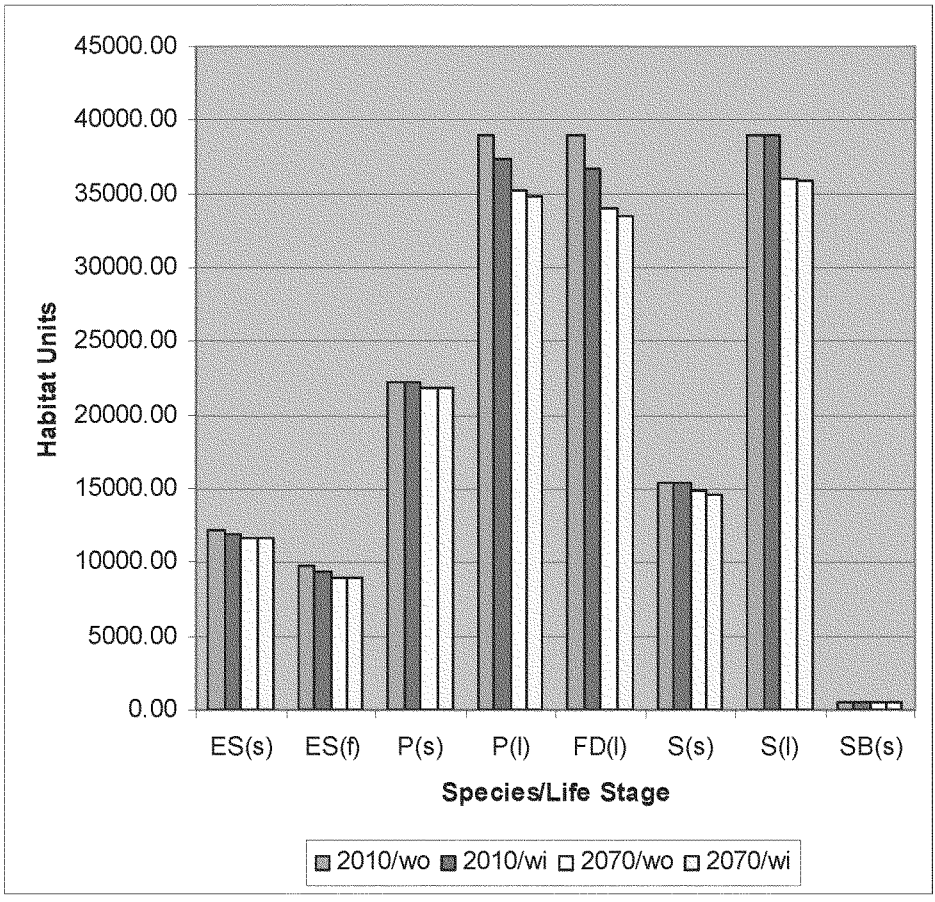


FIGURE 6
Utility Based High - Upper River

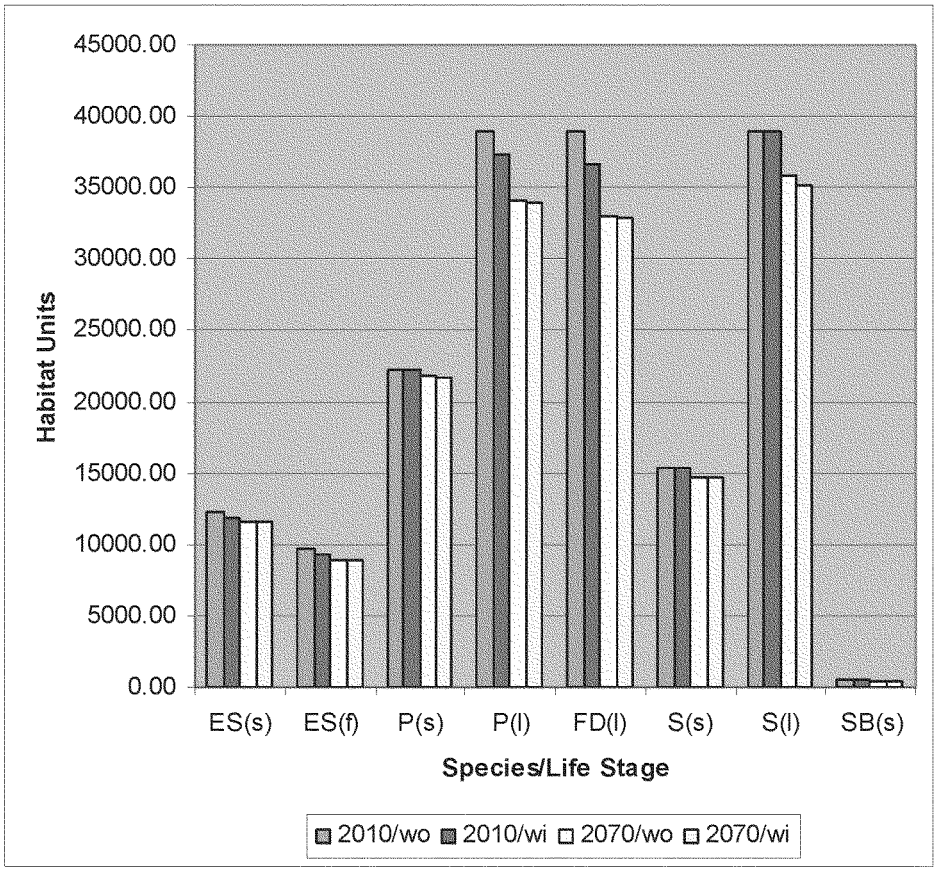


FIGURE 7
Clear Skies w/Hg - Middle River

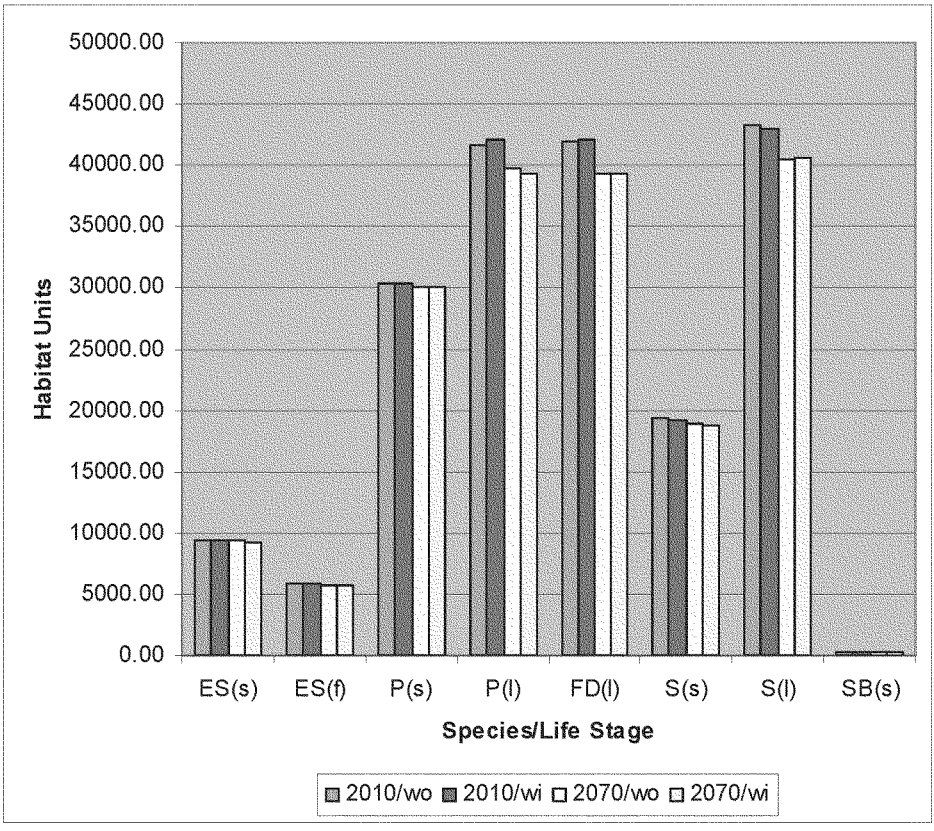


FIGURE 8
Clear Skies w/o Hg - Middle River

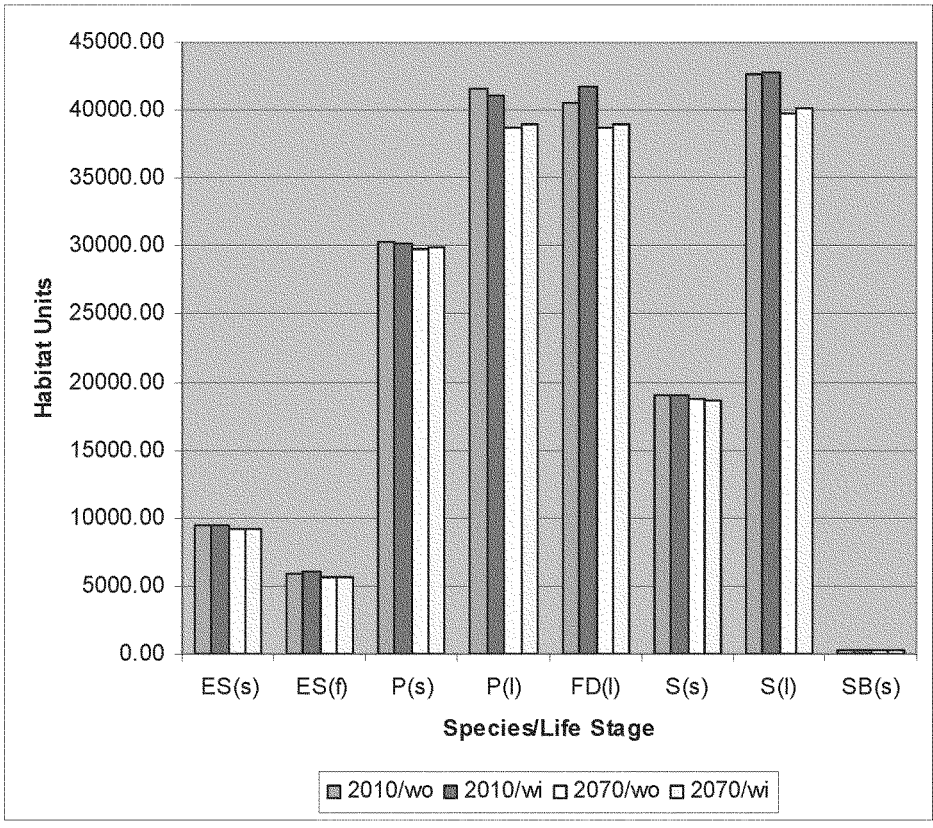


FIGURE 9
NAAQS - Middle River

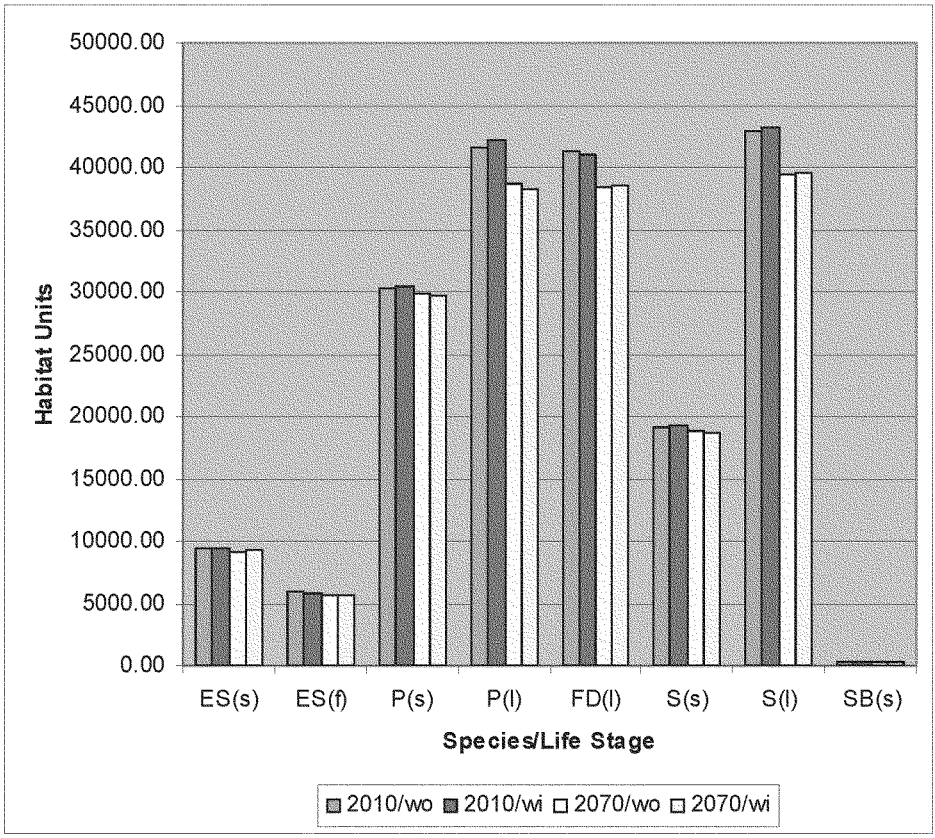


FIGURE 10
Utility Based (coal) - Middle River

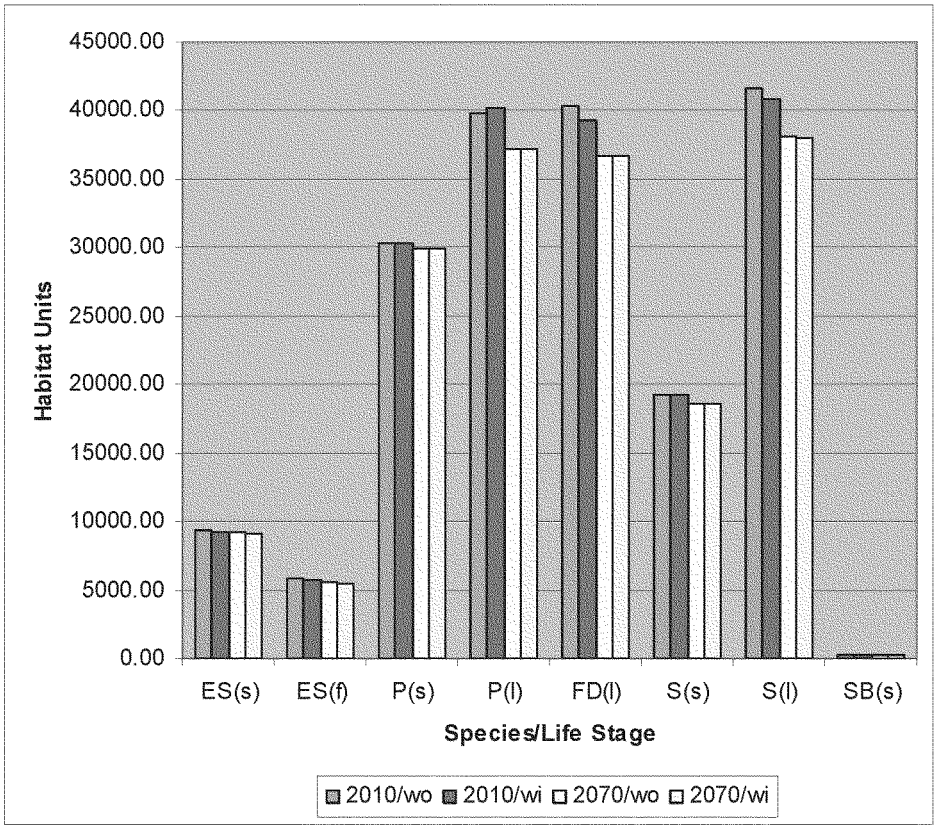


FIGURE11
Utility Based High - Middle River

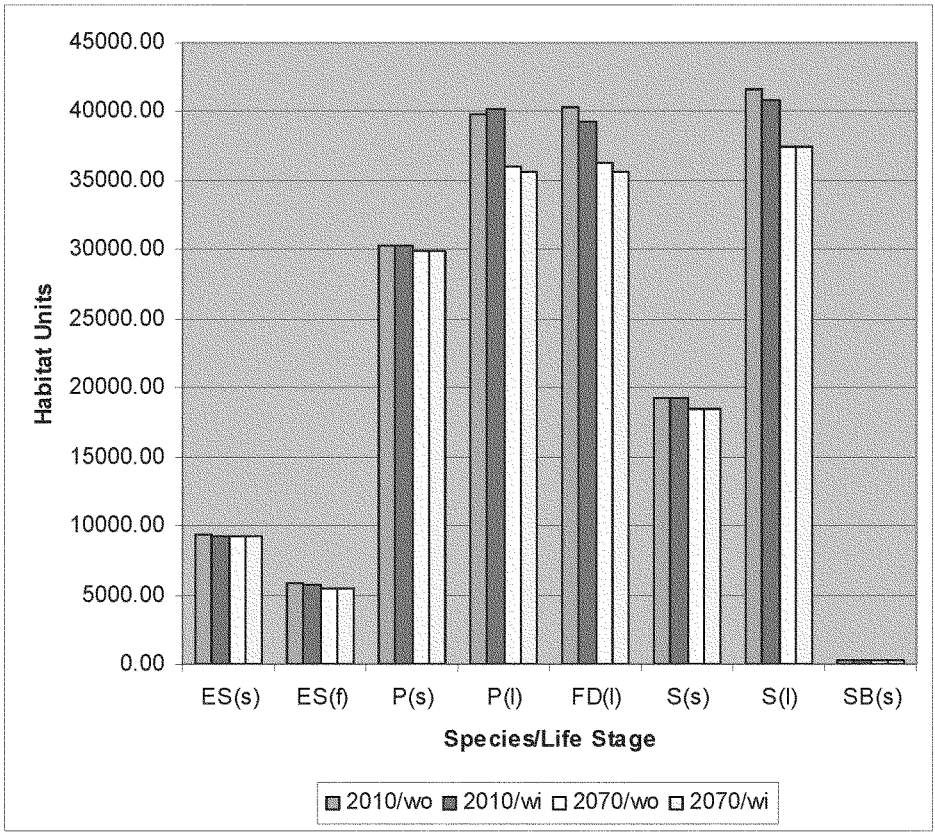


FIGURE 12
Clear Skies w/Hg - Lower River

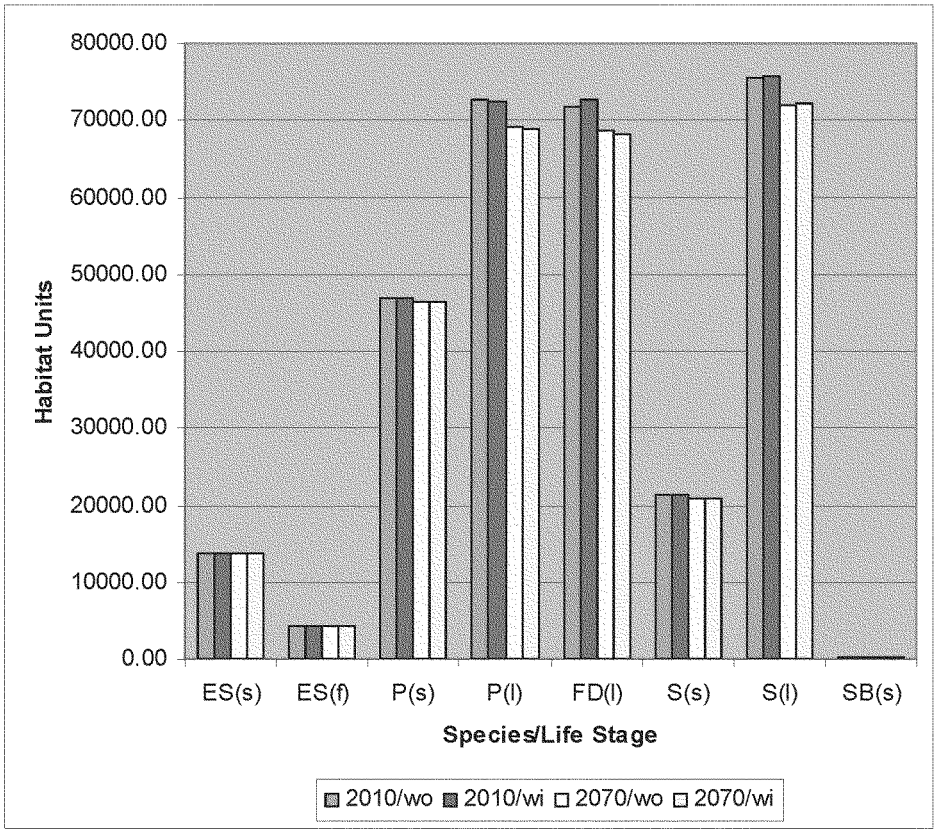


FIGURE 13
Clear Skies w/o Hg - Lower River

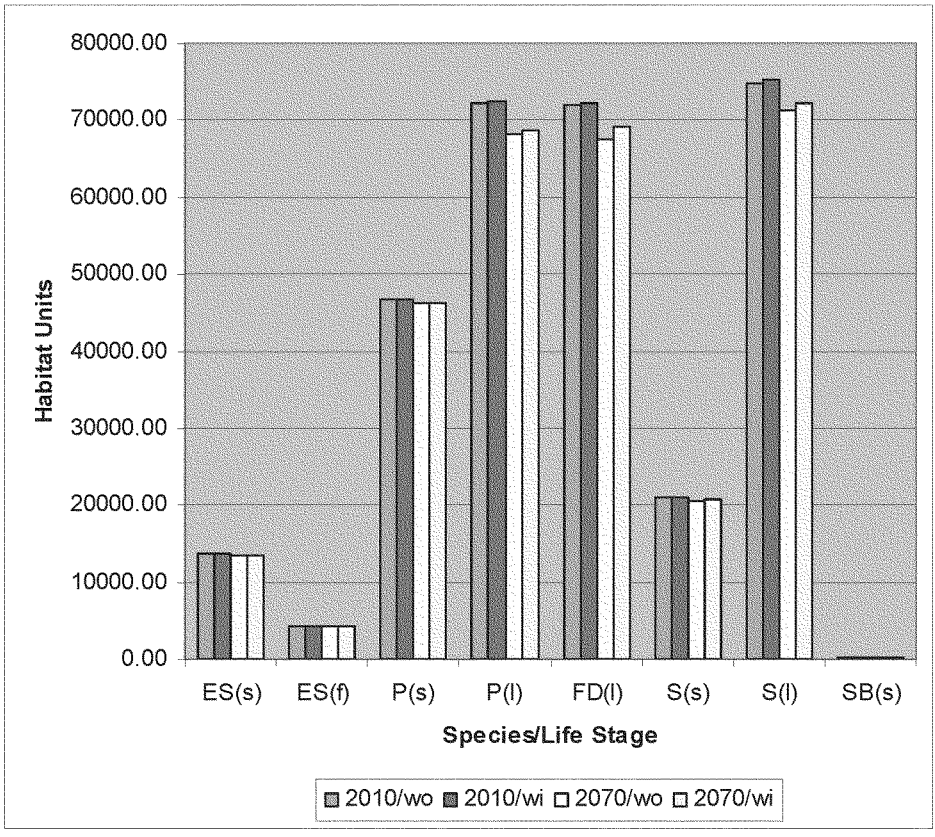


FIGURE 14
NAAQS - Lower River

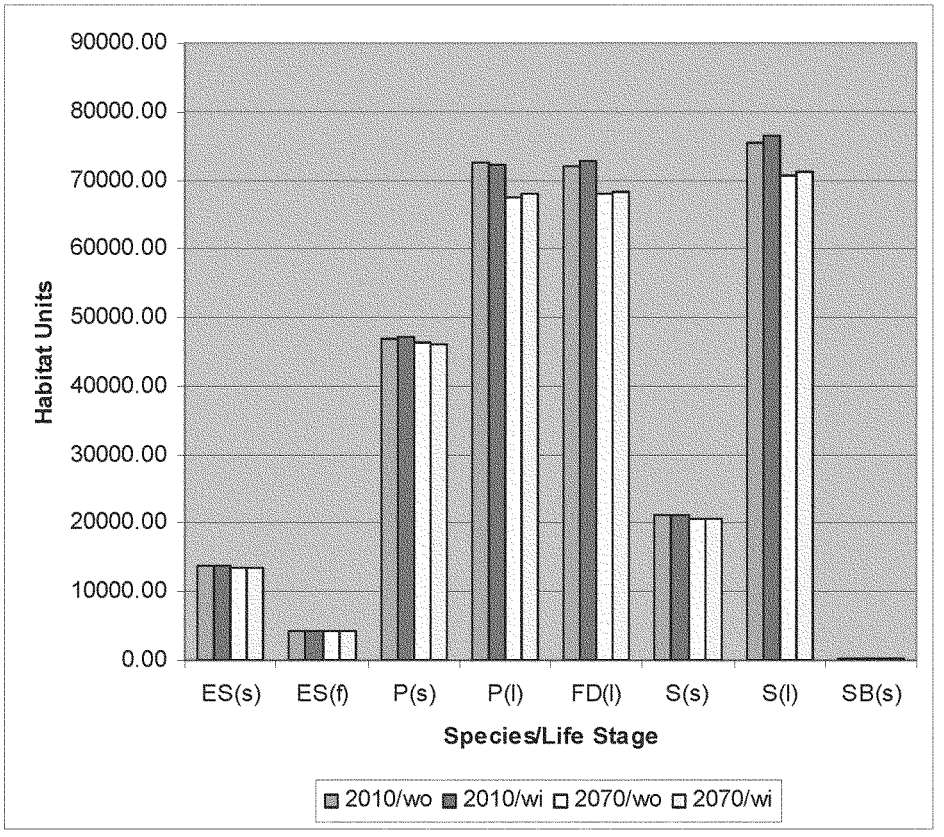


FIGURE 15
Utility Based (coal) - Lower River

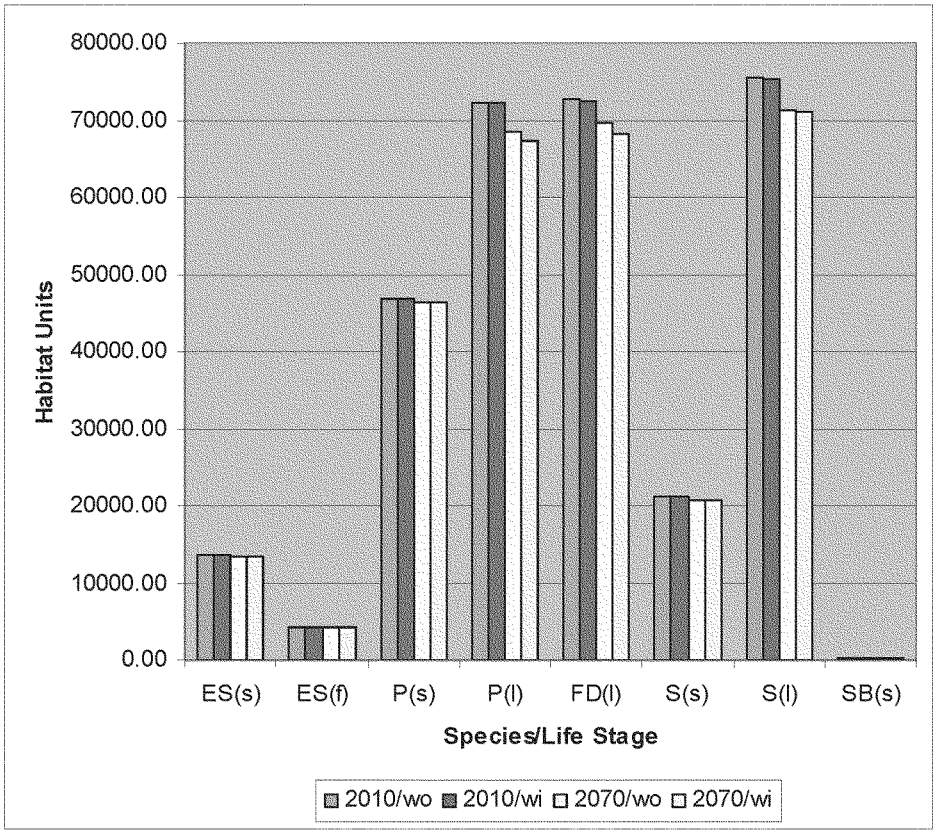


FIGURE 16
Utility Based High - Lower River

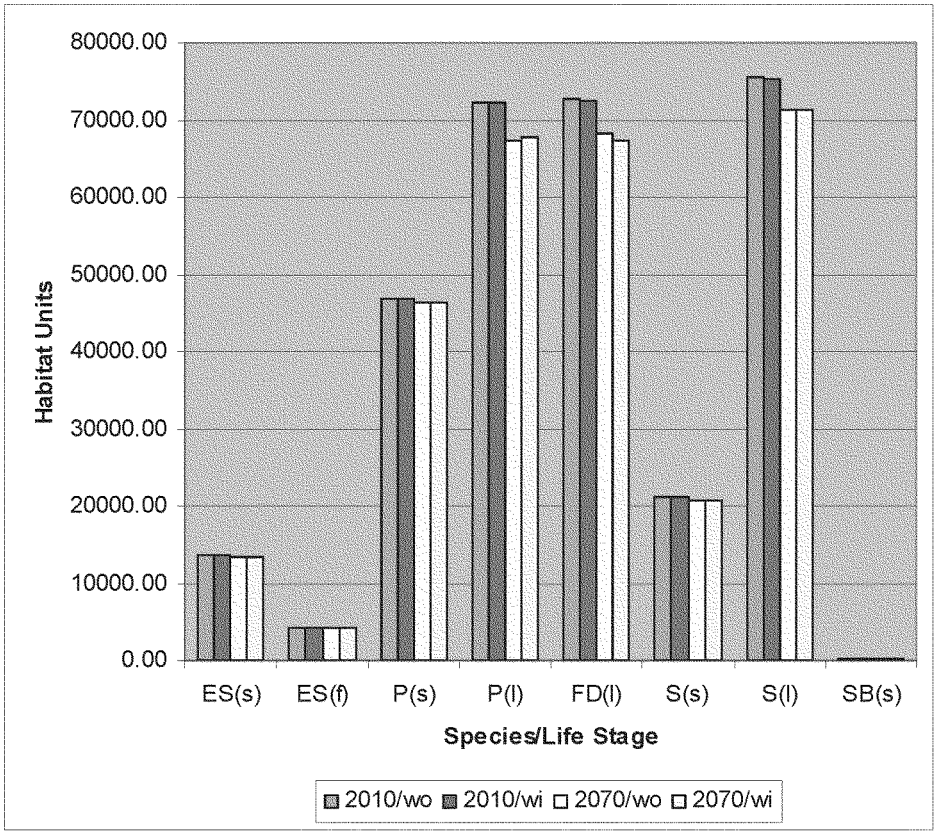
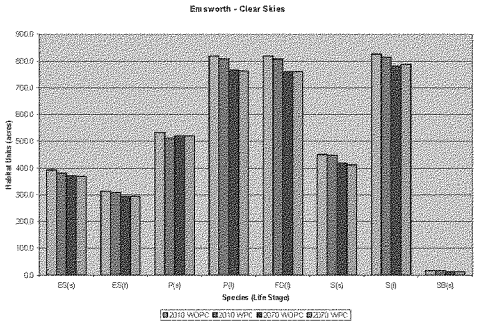
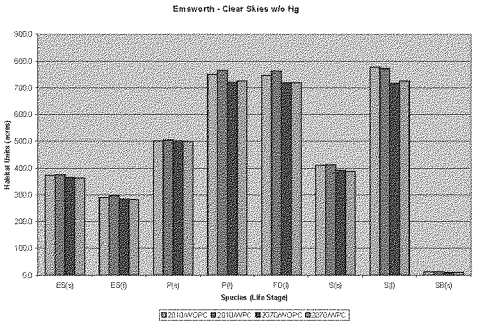
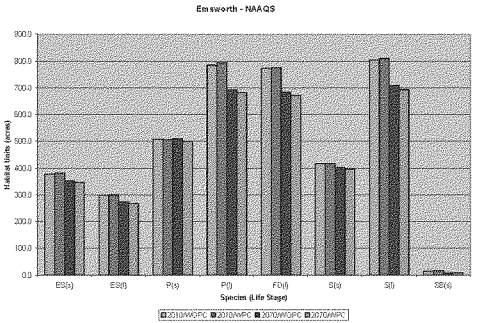
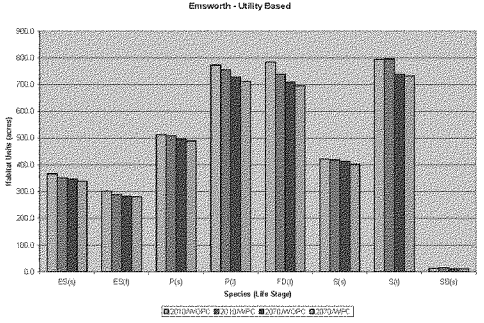


FIGURE 17
Emsworth Pool Long Term Comparisons









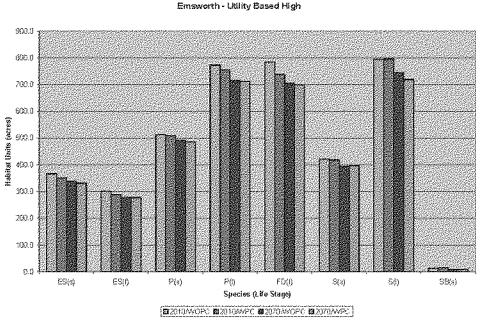
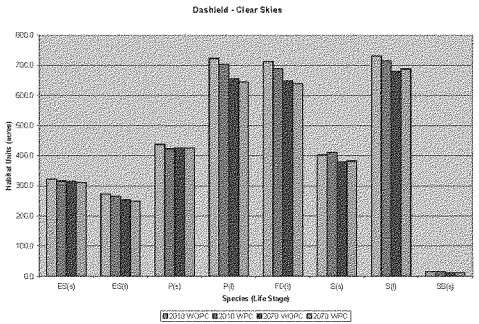
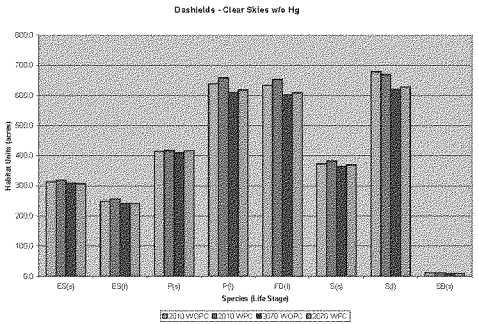
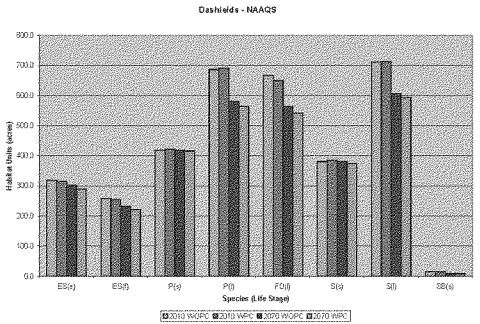
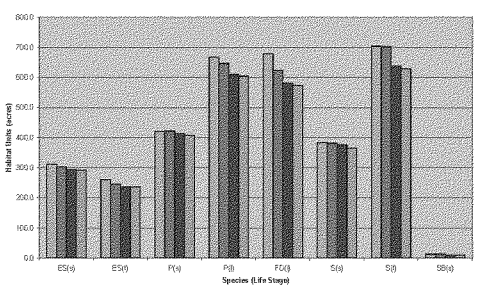


FIGURE 18
Dashields Pool Long Term Comparisons









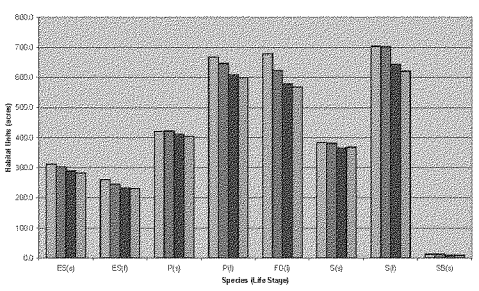
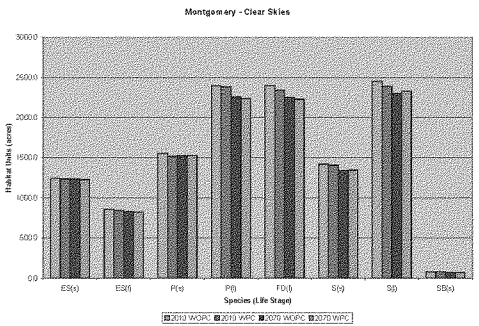
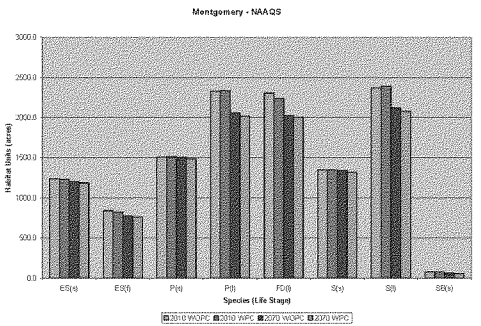
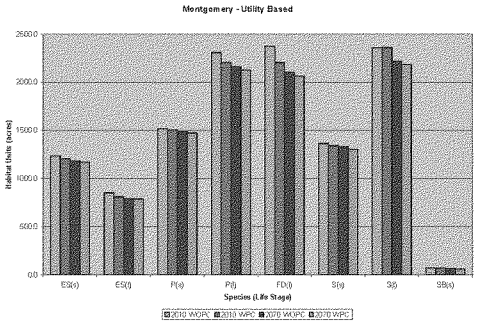


FIGURE 19
Montgomery Pool Long Term Comparisons







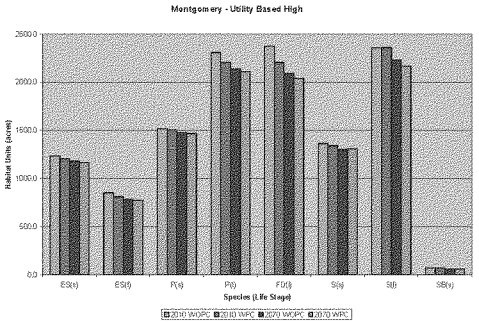


FIGURE 20
New Cumberland Pool Long Term Comparisons

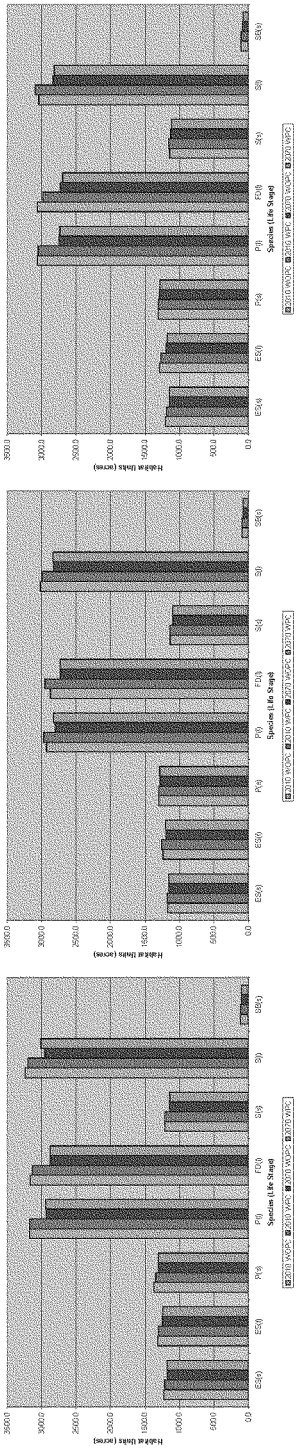
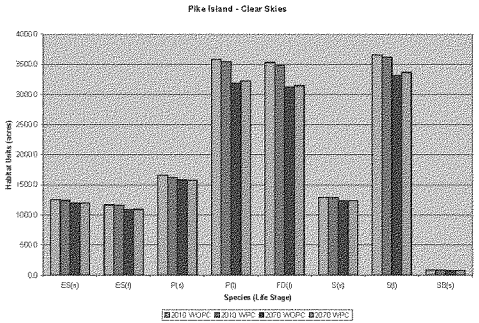
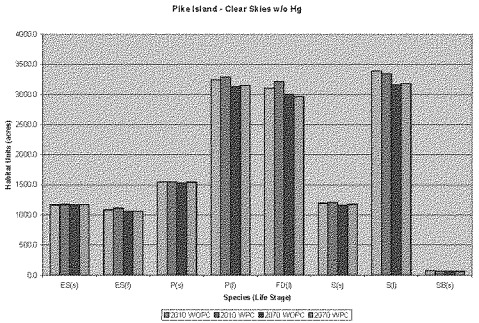
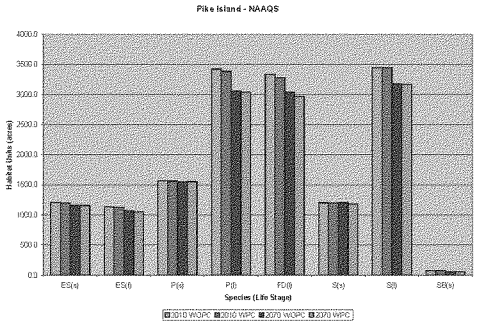
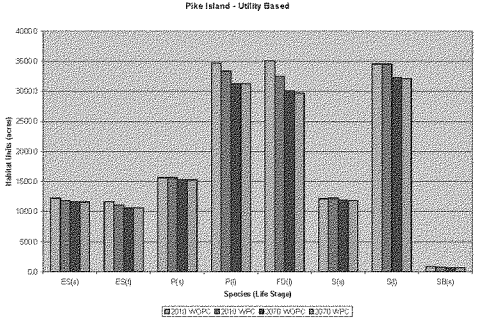


FIGURE 21
Pike Island Pool Long Term Comparisons









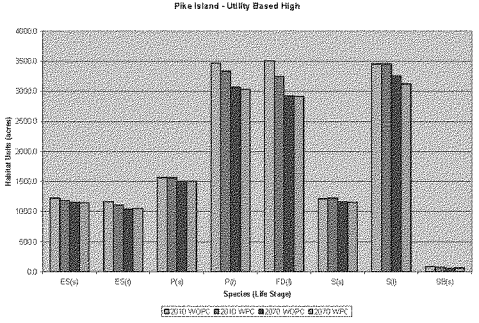
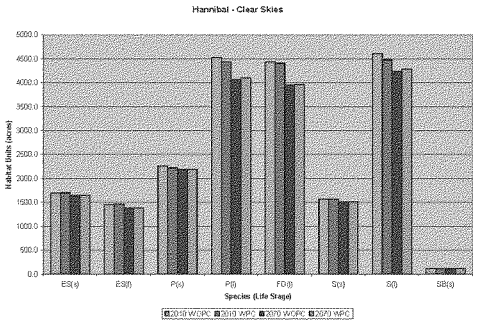
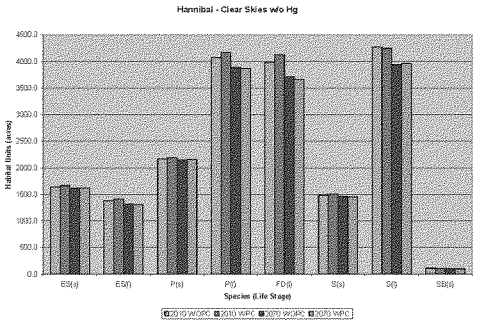
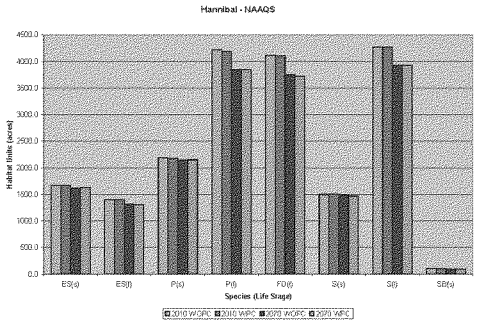
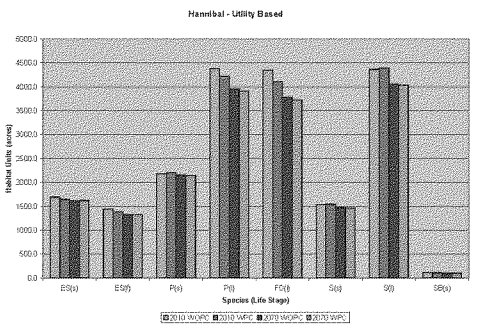


FIGURE 22
Hannibal Pool Long Term Comparisons









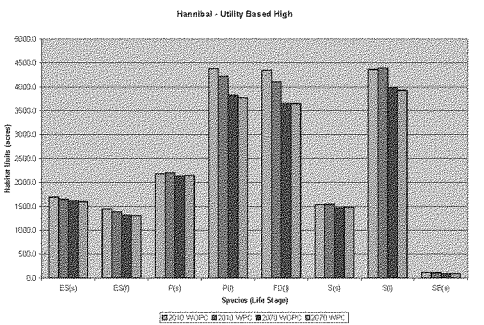
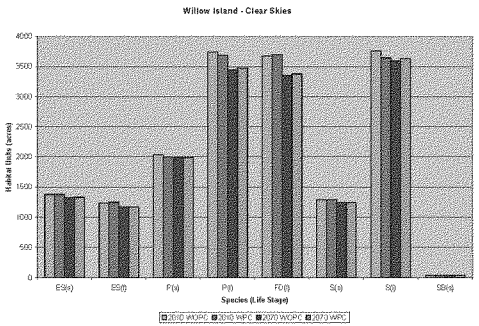
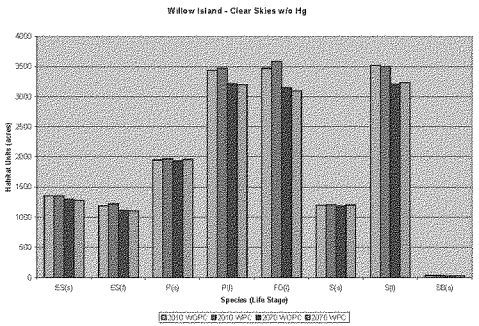
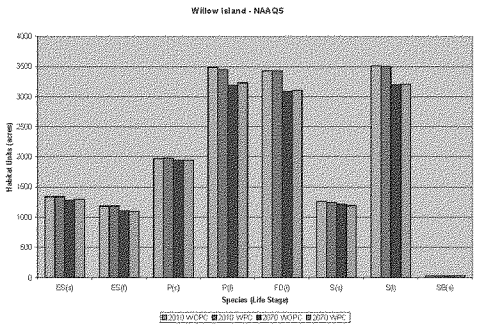
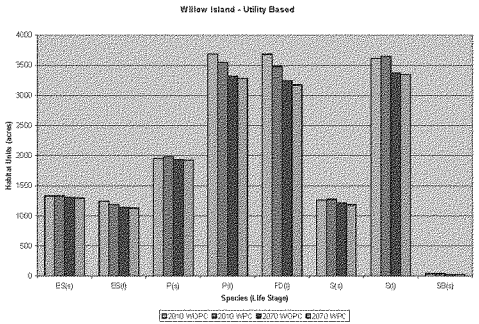


FIGURE 23
Willow Island Pool Long Term Comparisons









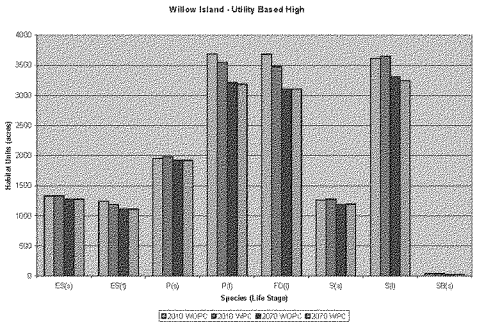
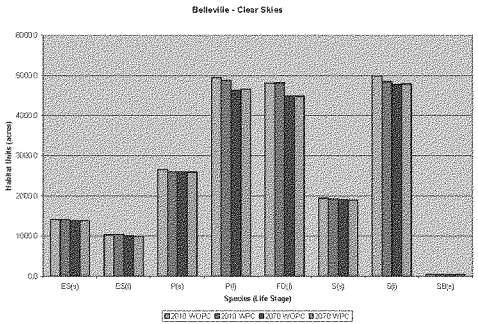
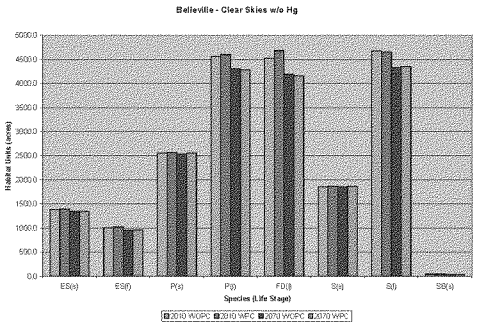
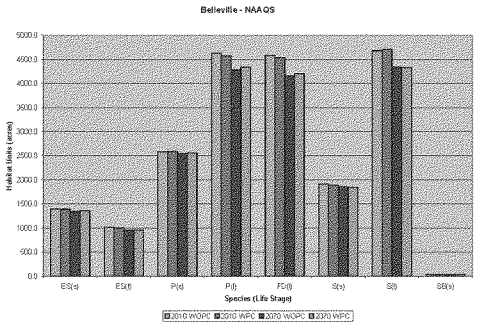
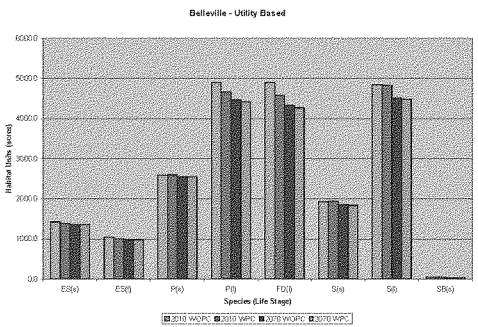


FIGURE 24
Belleville Pool Long Term Comparisons









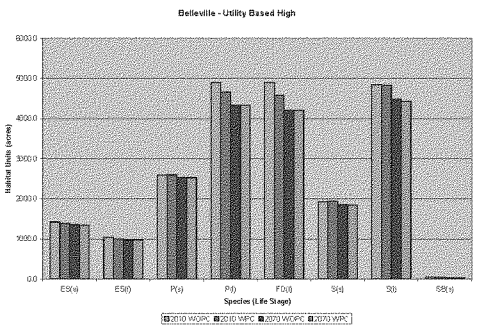
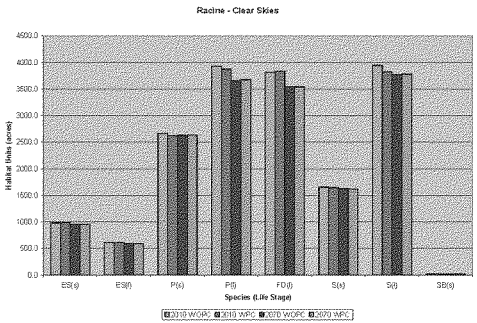
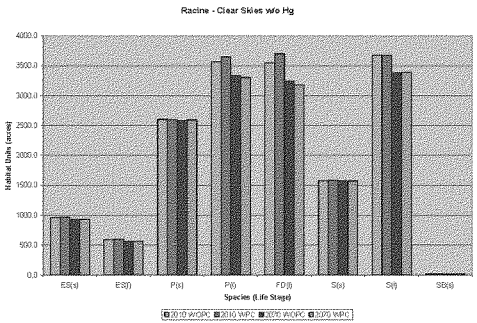
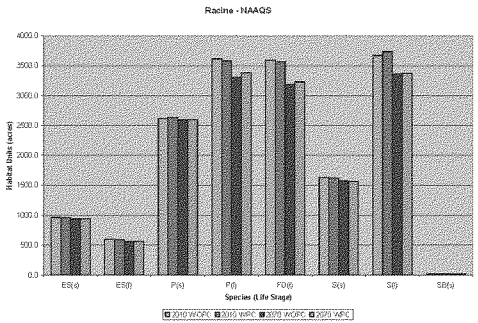
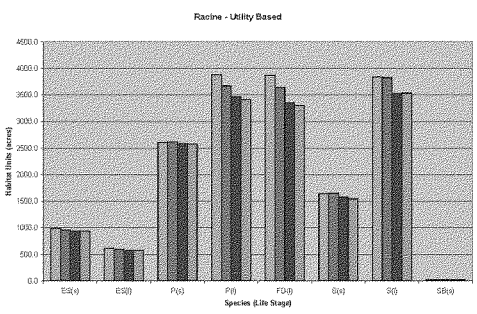


FIGURE 25
Racine Pool Long Term Comparisons









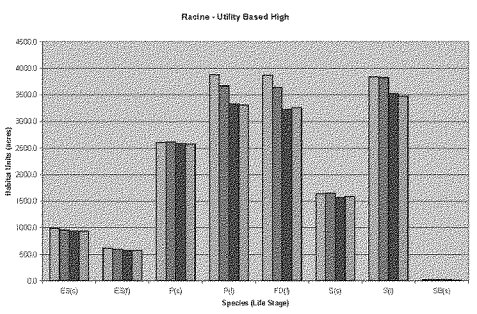
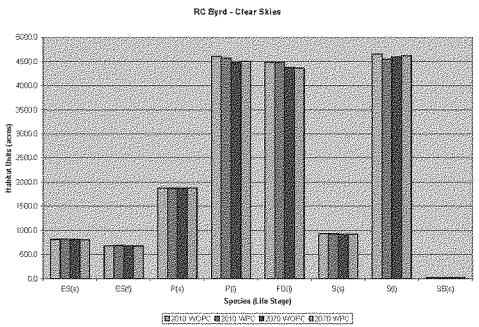
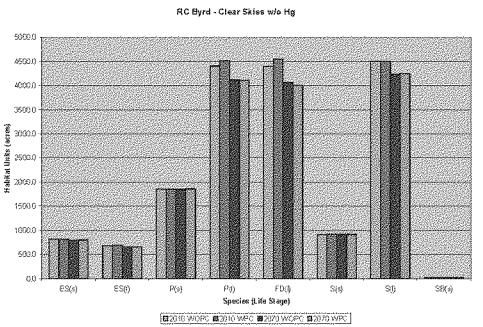
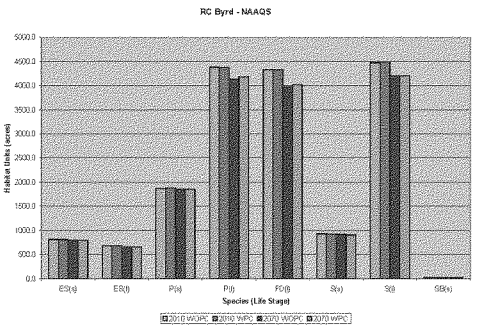
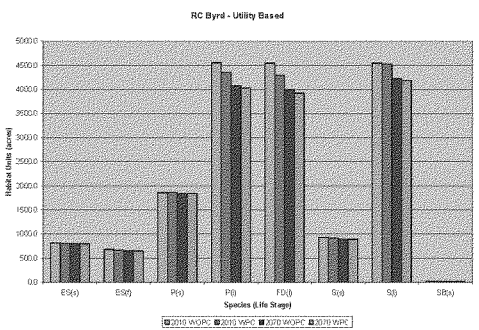


FIGURE 26
R C Byrd Pool Long Term Comparisons









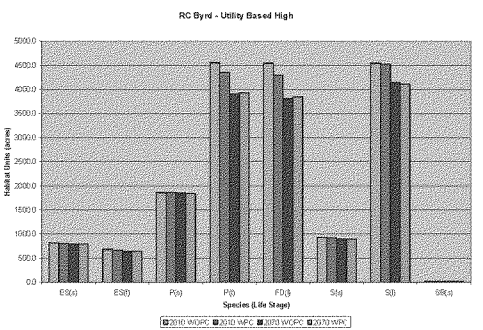
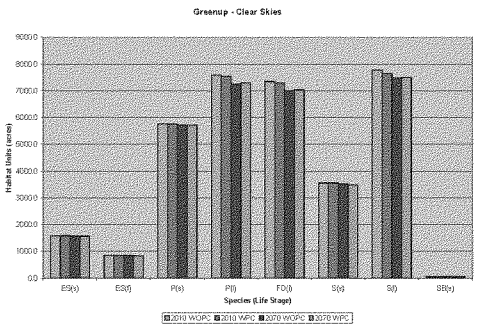
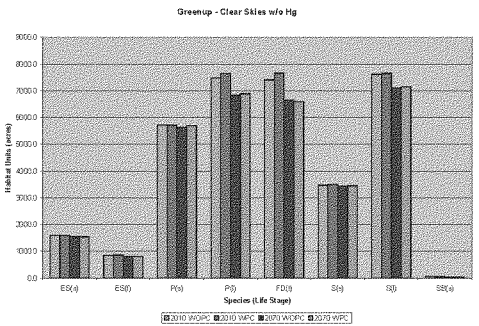
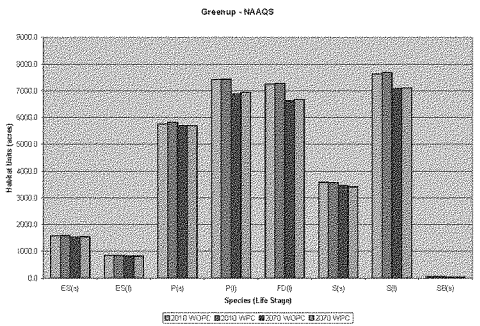
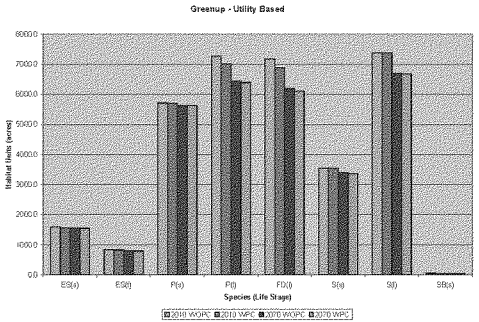


FIGURE 27
Greenup Pool Long Term Comparisons









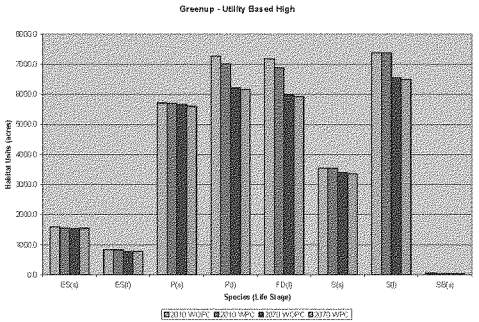
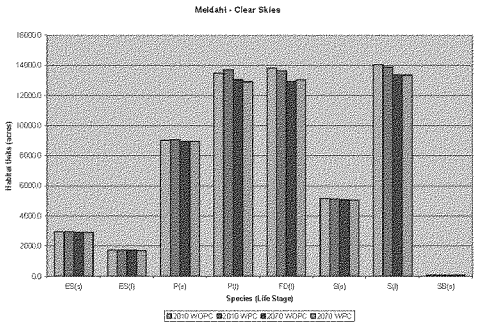
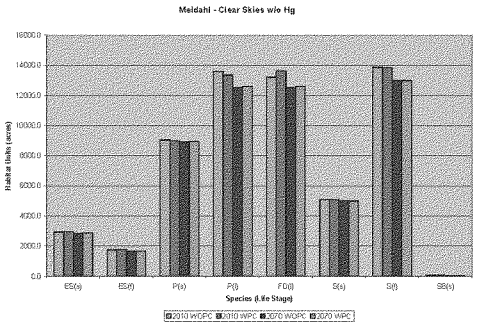
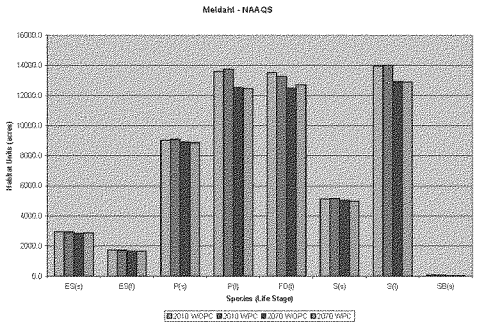
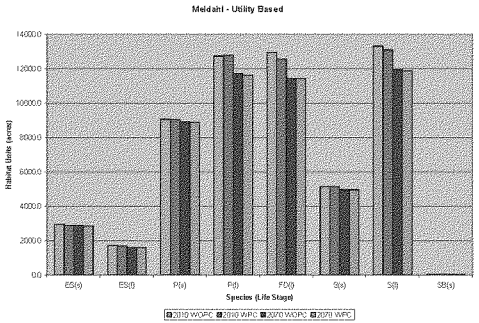


FIGURE 28
Meldahl Pool Long Term Comparisons









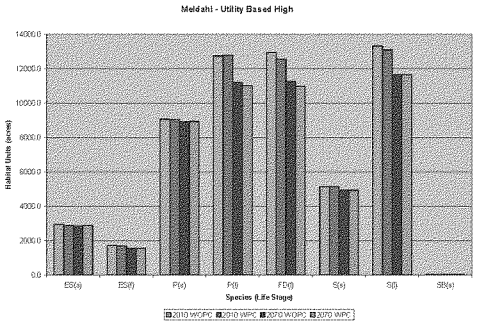
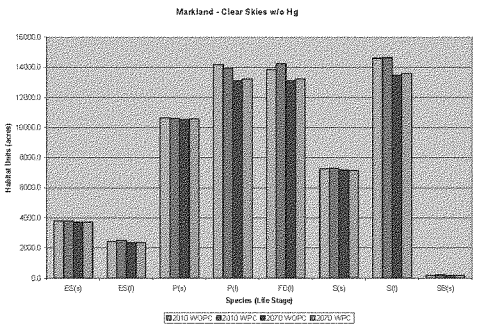
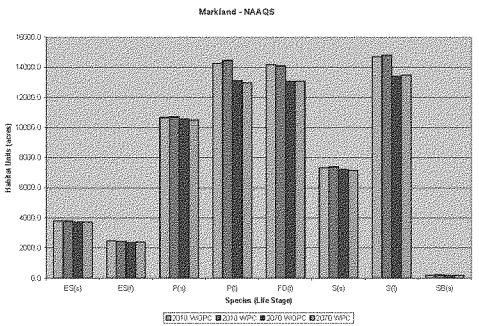
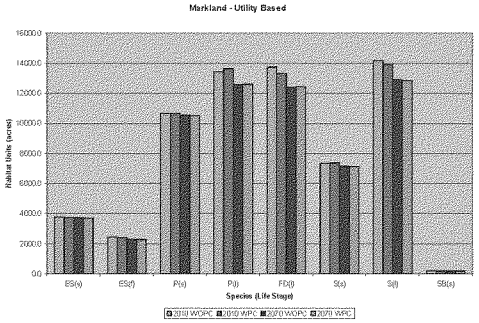


FIGURE 29
Markland Pool Long Term Comparisons







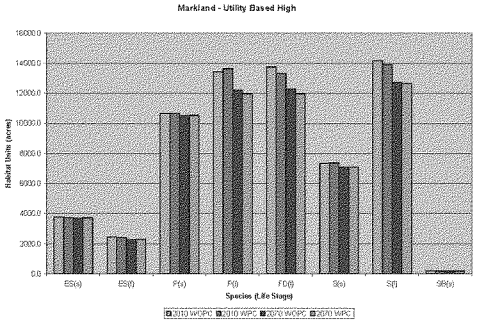
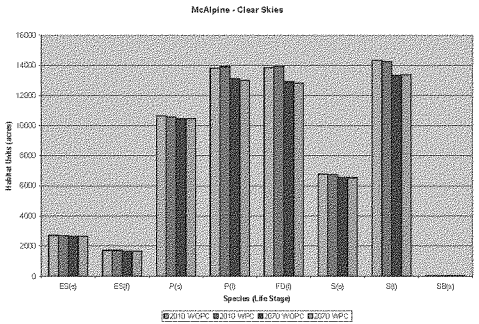
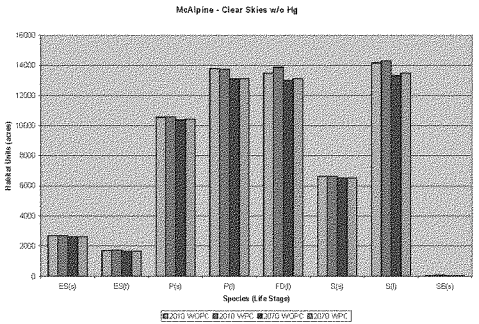
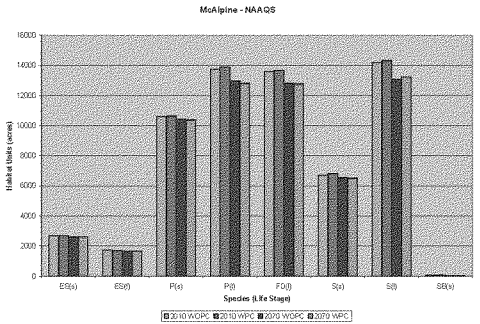
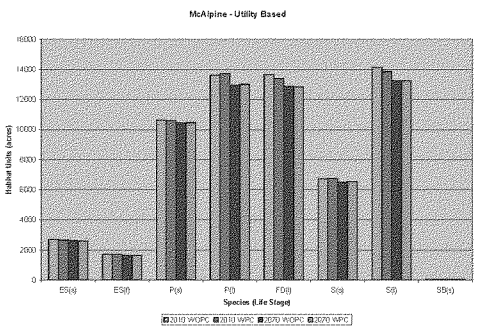


FIGURE 30
McAlpine Pool Long Term Comparisons









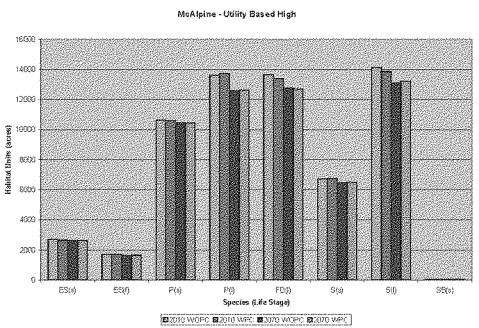
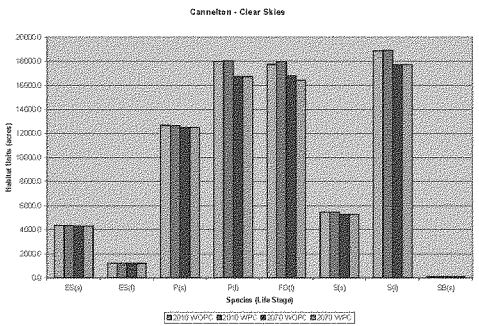
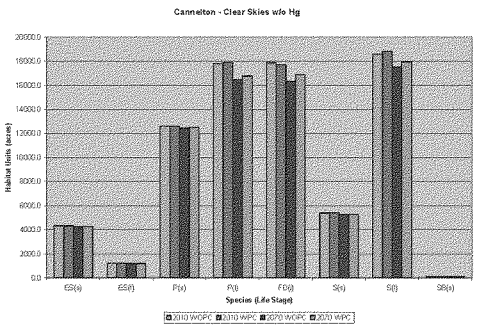
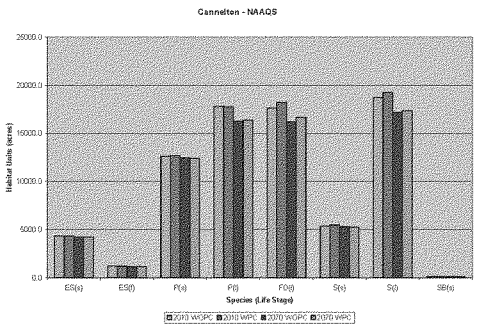
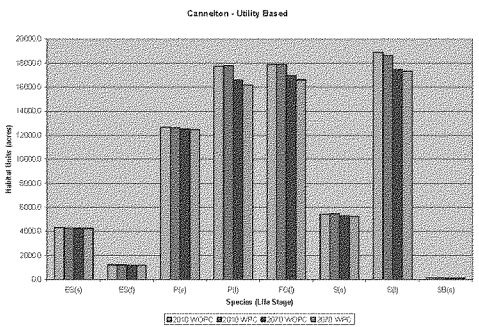


FIGURE 31
Cannelton Pool Long Term Comparisons









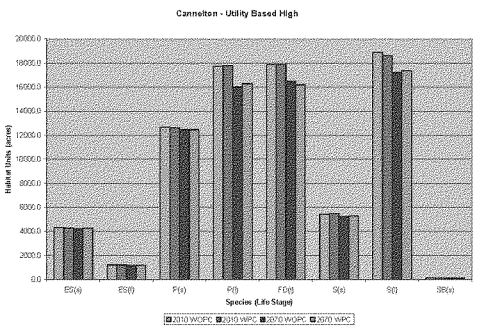
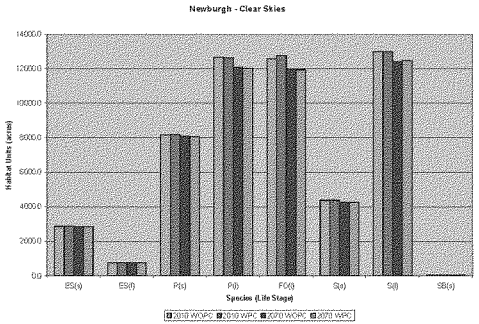
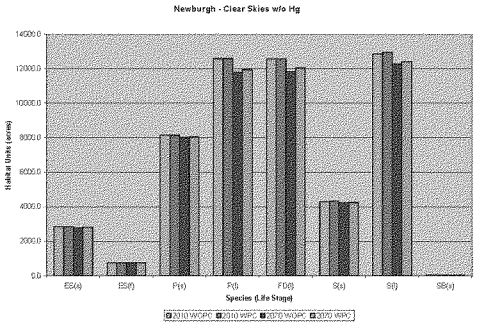
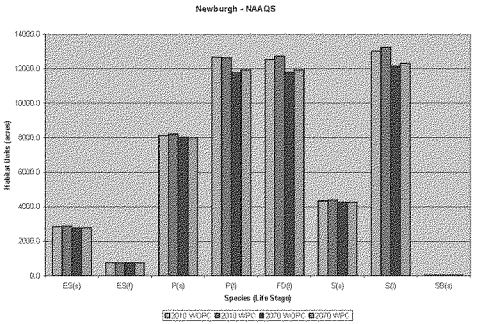
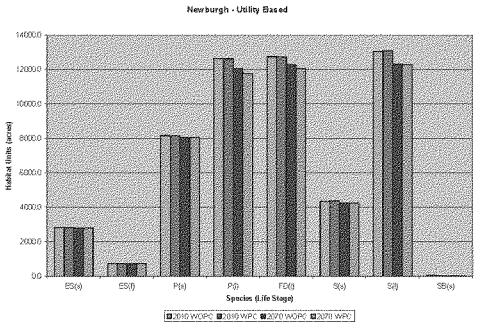


FIGURE 32
Newburgh Pool Long Term Comparisons









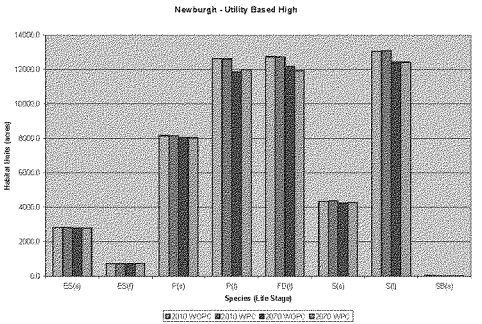
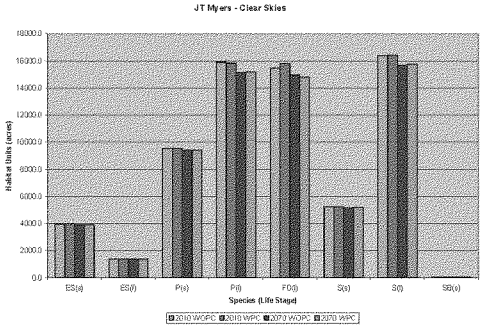
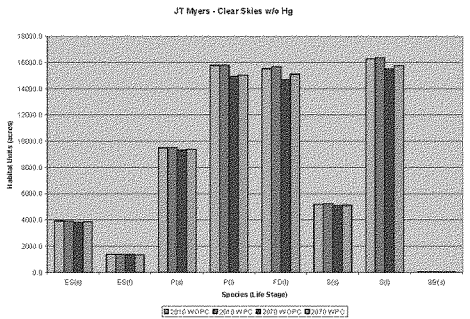
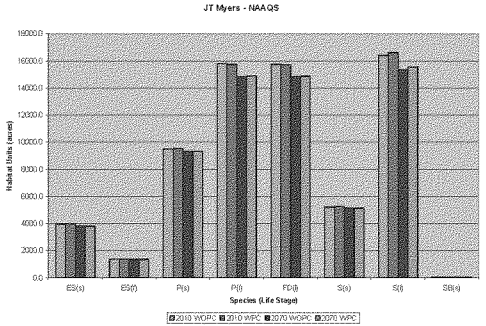
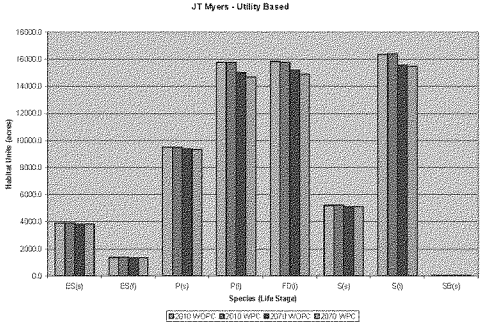


FIGURE 33
J T Myers Pool Long Term Comparisons









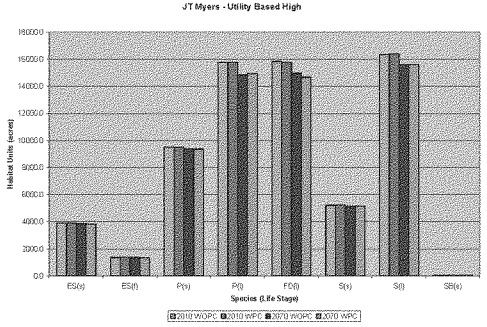
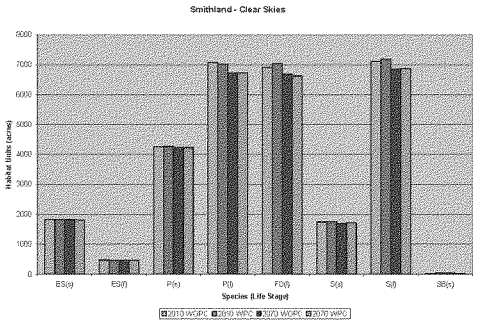
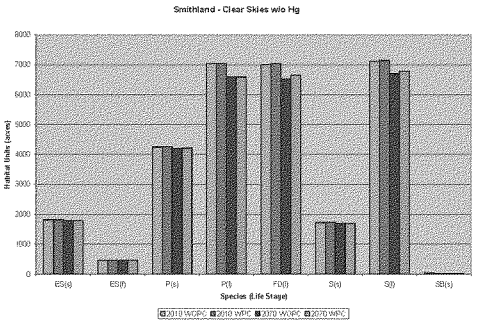
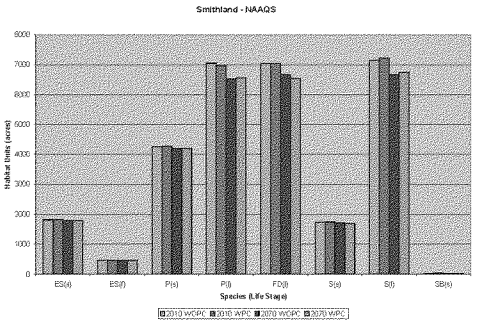
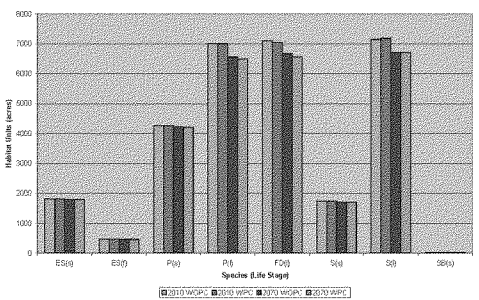


FIGURE 34
Smithland Pool Long Term Comparisons









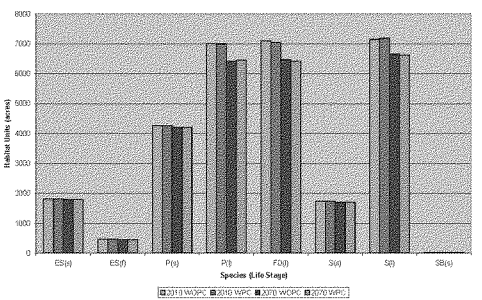
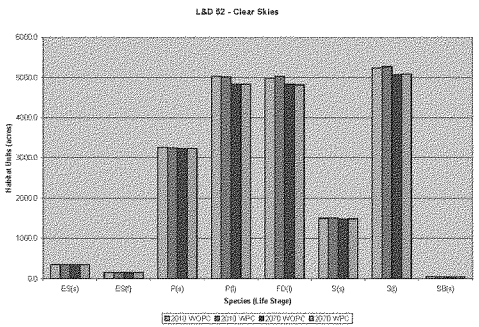
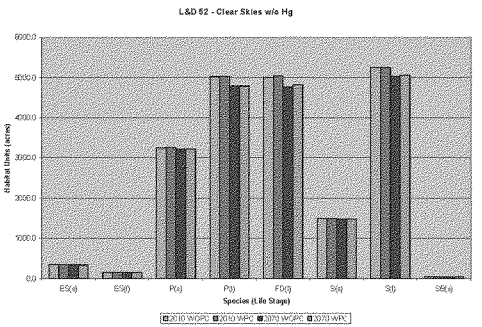
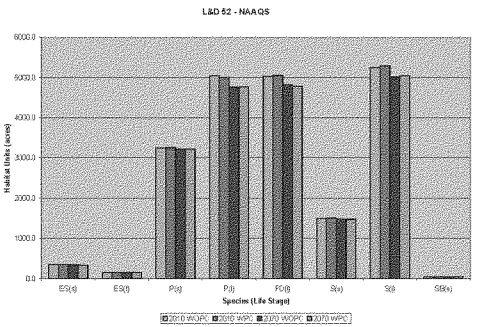
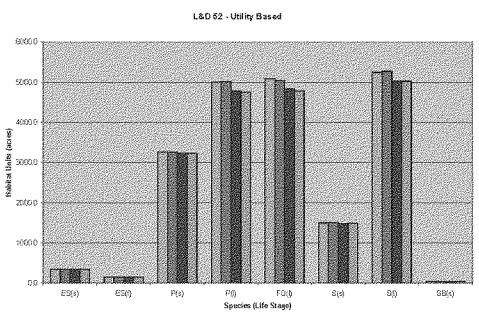


FIGURE 35
L&D#52 Pool Long Term Comparisons









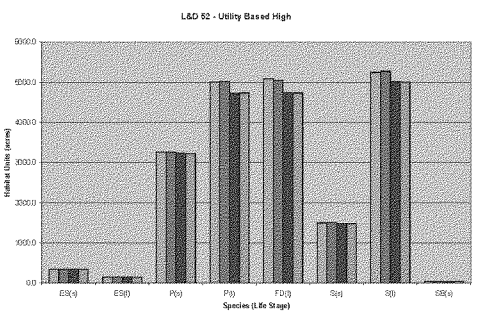
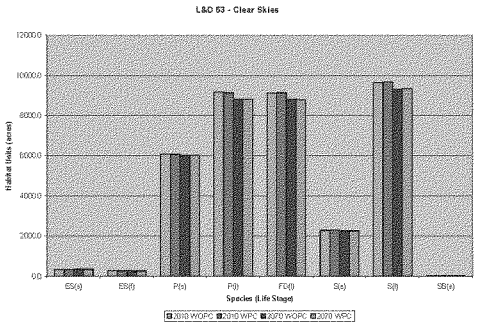
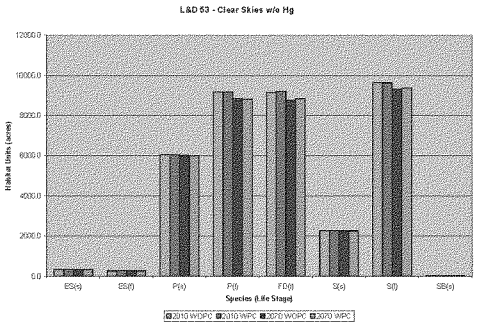
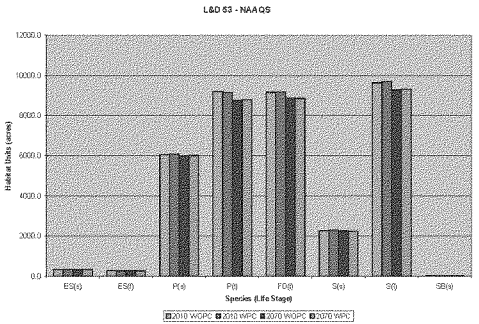
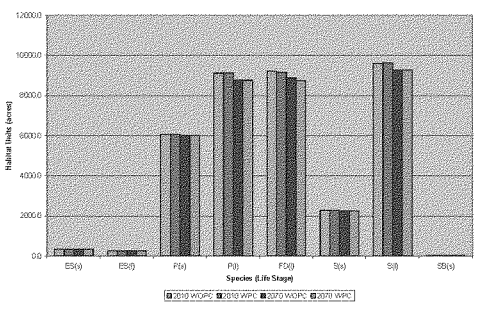


FIGURE 36
L&D#53 Pool Long Term Comparisons









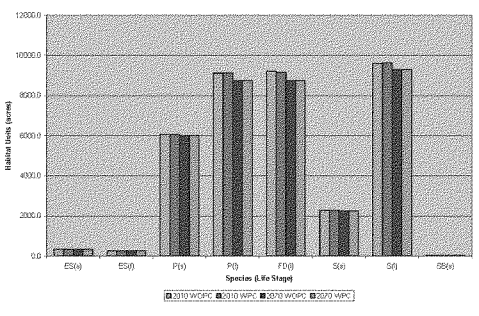


TABLE 7
Emsworth Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Emsworth	ES(s)	Clear Sky w/Hg	1.34	392.9	381.5	-11.4	-2.91%	364.6	365.6	1.1	0.29%	370.3	368.9	-1.4	-0.38%	392.90	370.30	-5.75%	381.48	368.90	-3.30%
	1	Clear Sky wo/Hg	1.34	372.7	375.7	3.0	0.80%	369.0	367.6	-1.4	-0.35%	363.9	362.6	-1.3	-0.37%	372.71	363.93	-2.36%	375.69	362.60	-3.48%
		NAAQS	1.34	376.5	380.8	4.3	1.13%	350.1	351.4	1.4	0.39%	351.6	345.4	-6.3	-1.78%	376.52	351.61	-6.62%	380.79	345.36	-9.30%
		Utility Based (Coal)	1.34	366.2	351.0	-15.2	-4.14%	351.0	346.1	-4.9	-1.39%	345.4	339.2	-6.2	-1.78%	366.20	345.37	-5.69%	351.04	339.21	-3.37%
		Utility Based High	1.34	366.2	351.0	-15.2	-4.14%	347.5	344.4	-3.1	-0.89%	338.7	331.4	-7.3	-2.17%	366.20	338.70	-7.51%	351.04	331.36	-5.60%
	ES(f)	Clear Sky w/Hg	1.59	312.9	308.5	-4.4	-1.39%	287.9	290.1	2.2	0.78%	294.7	294.4	-0.3	-0.10%	312.91	294.66	-5.83%	308.55	294.36	-4.60%
	2	Clear Sky wo/Hg	1.59	290.8	297.0	6.2	2.13%	294.2	294.2	0.0	-0.01%	284.0	282.4	-1.6	-0.56%	290.77	284.02	-2.32%	296.97	282.38	-4.91%
		NAAQS	1.59	298.4	299.6	1.2	0.39%	286.5	282.3	-4.2	-1.47%	273.6	266.9	-6.6	-2.43%	298.40	273.58	-8.32%	299.56	266.94	-10.89%
		Utility Based (Coal)	1.59	301.9	288.0	-13.9	-4.60%	293.3	291.4	-1.9	-0.65%	281.7	280.2	-1.5	-0.52%	301.90	281.71	-6.69%	288.01	280.25	-2.69%
		Utility Based High	1.59	301.9	288.0	-13.9	-4.60%	282.4	286.8	4.4	1.57%	278.8	277.2	-1.5	-0.55%	301.90	278.79	-7.65%	288.01	277.25	-3.74%
	P(s)	Clear Sky w/Hg	0.56	533.1	511.8	-21.3	-3.99%	516.2	509.0	-7.2	-1.40%	520.9	519.5	-1.4	-0.26%	533.06	520.89	-2.28%	511.80	519.51	1.51%
	3	Clear Sky wo/Hg	0.56	502.3	504.8	2.4	0.48%	509.6	508.1	-1.4	-0.28%	502.1	498.6	-3.5	-0.70%	502.35	502.15	-0.04%	504.78	498.65	-1.21%
		NAAQS	0.56	508.3	505.5	-2.8	-0.55%	513.9	516.7	2.8	0.55%	509.6	499.4	-10.2	-2.00%	508.28	509.59	0.26%	505.49	499.38	-1.21%
		Utility Based (Coal)	0.56	512.0	508.2	-3.8	-0.75%	495.4	501.6	6.2	1.25%	495.8	489.0	-6.8	-1.37%	512.04	495.80	-3.17%	508.21	489.03	-3.77%
		Utility Based High	0.56	512.0	508.2	-3.8	-0.75%	497.4	495.6	-1.8	-0.35%	491.7	486.0	-5.7	-1.16%	512.04	491.74	-3.97%	508.21	486.04	-4.36%
	P(l)	Clear Sky w/Hg	0.50	818.4	808.6	-9.9	-1.20%	757.7	758.9	1.3	0.17%	767.2	763.6	-3.5	-0.46%	818.43	767.16	-6.26%	808.57	763.61	-5.56%
	4	Clear Sky wo/Hg	0.50	749.9	764.8	14.9	1.99%	734.3	745.2	10.9	1.48%	721.3	725.8	4.5	0.63%	749.90	721.27	-3.82%	764.81	725.80	-5.10%
		NAAQS	0.50	784.3	794.4	10.1	1.29%	719.6	718.9	-0.7	-0.09%	691.9	681.4	-10.5	-1.52%	784.29	691.91	-11.78%	794.39	681.36	-14.23%
		Utility Based (Coal)	0.50	772.7	755.5	-17.2	-2.22%	762.2	752.9	-9.2	-1.21%	729.1	712.1	-17.0	-2.33%	772.67	729.09	-5.64%	755.50	712.08	-5.75%
		Utility Based High	0.50	772.7	755.5	-17.2	-2.22%	745.4	743.9	-1.5	-0.20%	715.1	711.5	-3.6	-0.50%	772.67	715.06	-7.46%	755.50	711.46	-5.83%
	FD(l)	Clear Sky w/Hg	0.51	818.2	807.3	-10.9	-1.33%	747.4	754.3	6.9	0.93%	760.7	760.4	-0.2	-0.03%	818.20	760.65	-7.03%	807.30	760.44	-5.80%
	6	Clear Sky wo/Hg	0.51	745.9	763.0	17.1	2.30%	760.9	766.1	5.3	0.69%	718.3	719.5	1.2	0.16%	745.87	718.30	-3.70%	763.01	719.45	-5.71%
		NAAQS	0.51	773.1	775.8	2.7	0.35%	732.1	719.3	-12.8	-1.75%	684.0	670.9	-13.1	-1.92%	773.10	683.99	-11.53%	775.79	670.88	-13.52%
		Utility Based (Coal)	0.51	784.6	739.4	-45.3	-5.77%	754.2	742.8	-11.4	-1.52%	709.8	695.5	-14.3	-2.01%	784.63	709.82	-9.54%	739.36	695.54	-5.93%
		Utility Based High	0.51	784.6	739.4	-45.3	-5.77%	715.9	729.8	13.9	1.94%	704.4	698.6	-5.8	-0.82%	784.63	704.44	-10.22%	739.36	698.63	-5.51%
	S(s)	Clear Sky w/Hg	0.86	450.8	447.7	-3.1	-0.70%	414.3	412.3	-2.0	-0.49%	418.2	411.7	-6.5	-1.56%	450.84	418.19	-7.24%	447.69	411.68	-8.04%
	7	Clear Sky wo/Hg	0.86	410.7	413.1	2.5	0.60%	410.0	407.9	-2.0	-0.49%	390.9	387.2	-3.7	-0.94%	410.68	390.90	-4.83%	413.14	387.25	-6.27%
		NAAQS	0.86	416.9	417.3	0.4	0.10%	403.8	402.2	-1.6	-0.39%	401.2	395.1	-6.1	-1.51%	416.85	401.17	-3.76%	417.25	395.10	-5.31%
		Utility Based (Coal)	0.86	421.8	418.6	-3.2	-0.75%	399.0	412.8	13.8	3.47%	413.6	401.6	-12.0	-2.91%	421.76	413.60	-1.93%	418.60	401.55	-4.07%
		Utility Based High	0.86	421.8	418.6	-3.2	-0.75%	392.4	397.7	5.3	1.35%	394.3	397.8	3.4	0.87%	421.76	394.35	-6.50%	418.60	397.77	-4.98%
	S(l)	Clear Sky w/Hg	0.50	825.9	814.4	-11.5	-1.39%	782.5	782.0	-0.5	-0.07%	781.0	787.2	6.2	0.79%	825.92	781.02	-5.44%	814.41	787.22	-3.34%
	8	Clear Sky wo/Hg	0.50	777.5	772.1	-5.4	-0.69%	747.3	753.8	6.5	0.87%	717.6	725.2	7.7	1.07%	777.49	717.56	-7.71%	772.11	725.23	-6.07%
		NAAQS	0.50	804.4	809.7	5.3	0.67%	738.3	733.8	-4.6	-0.62%	708.2	693.1	-15.1	-2.13%	804.36	708.20	-11.96%	809.71	693.13	-14.40%
		Utility Based (Coal)	0.50	794.1	795.9	1.7	0.22%	773.1	761.2	-12.0	-1.55%	738.2	732.5	-5.7	-0.77%	794.13	738.18	-7.04%	795.87	732.48	-7.98%
		Utility Based High	0.50	794.1	795.9	1.7	0.22%	750.6	756.3	5.7	0.76%	744.2	718.9	-25.3	-3.40%	794.13	744.20	-6.29%	795.87	718.93	-9.67%
	SB(s)	Clear Sky w/Hg	1.97	16.3	16.6	0.3	2.03%	12.8	12.8	0.0	-0.12%	11.8	11.7	0.0	-0.35%	16.26	11.76	-27.67%	16.59	11.72	-29.36%
	14	Clear Sky wo/Hg	1.97	11.8	12.6	0.8	6.65%	12.2	12.4	0.2	1.49%	9.1	10.0	0.8	9.07%	11.80	9.12	-22.69%	12.58	9.95	-20.93%
		NAAQS	1.97	14.5	16.2	1.6	11.24%	10.3	10.3	-0.1	-0.65%	7.9	8.2	0.4	4.84%	14.53	7.85	-45.94%	16.16	8.23	-49.06%
		Utility Based (Coal)	1.97	13.2	14.9	1.7	13.28%	12.0	11.9	-0.1	-0.92%	10.0	10.5	0.5	5.05%	13.15	10.02	-23.80%	14.90	10.53	-29.34%
		Utility Based High	1.97	13.2	14.9	1.7	13.28%	12.1	12.7	0.6	4.59%	8.2	8.9	0.6	7.89%	13.15	8.22	-37.50%	14.90	8.87	-40.48%

[1]ES(s)=Emerald Shiner(spawning); ES(f)=Emerald Shiner (fry); P(s)=Paddlefish(spawning); P(l)=Paddlefish(larval); FD(l)=Freshwater Drum(larval); S(s)=Sauger(spawning); S(l)=Sauger(larval); SB(s)=Spotted Bass(spawning)

TABLE 8
Dashields Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Dashields	ES(s)	Clear Sky w/Hg	1.20	322.2	316.0	-6.2	-1.92%	309.8	309.0	-0.8	-0.26%	314.4	312.0	-2.4	-0.75%	322.22	314.40	-2.43%	316.03	312.03	-1.26%
	1	Clear Sky wo/Hg	1.20	313.4	319.2	5.8	1.85%	308.3	306.8	-1.5	-0.49%	308.8	306.8	-2.0	-0.65%	313.37	308.83	-1.45%	319.15	306.83	-3.86%
		NAAQS	1.20	318.2	315.4	-2.8	-0.87%	299.8	299.3	-0.6	-0.19%	302.3	289.2	-13.0	-4.31%	318.20	302.27	-5.01%	315.42	289.23	-8.30%
		Utility Based (Coal)	1.20	312.0	302.2	-9.8	-3.14%	296.9	299.3	2.4	0.81%	293.5	292.4	-1.1	-0.38%	312.00	293.55	-5.91%	302.21	292.43	-3.23%
		Utility Based High	1.20	312.0	302.2	-9.8	-3.14%	291.2	293.6	2.4	0.82%	288.8	282.6	-6.2	-2.15%	312.00	288.79	-7.44%	302.21	282.59	-6.49%
	ES(f)	Clear Sky w/Hg	1.47	273.0	264.6	-8.4	-3.07%	245.5	247.1	1.7	0.68%	253.4	249.3	-4.1	-1.62%	273.02	253.40	-7.18%	264.65	249.29	-5.80%
	2	Clear Sky wo/Hg	1.47	249.4	256.0	6.6	2.64%	248.2	247.7	-0.5	-0.20%	240.7	240.9	0.2	0.09%	249.41	240.68	-3.50%	255.98	240.89	-5.90%
		NAAQS	1.47	258.5	254.7	-3.8	-1.49%	241.9	237.5	-4.4	-1.80%	231.1	221.3	-9.8	-4.26%	258.54	231.11	-10.61%	254.69	221.26	-13.12%
		Utility Based (Coal)	1.47	260.5	245.1	-15.3	-5.89%	251.0	248.2	-2.7	-1.09%	235.8	237.1	1.3	0.57%	260.48	235.76	-9.49%	245.14	237.09	-3.28%
		Utility Based High	1.47	260.5	245.1	-15.3	-5.89%	237.9	241.1	3.2	1.37%	233.2	231.1	-2.2	-0.93%	260.48	233.24	-10.46%	245.14	231.06	-5.74%
	P(s)	Clear Sky w/Hg	0.48	437.6	422.8	-14.8	-3.39%	429.4	427.1	-2.2	-0.52%	425.1	425.9	0.8	0.18%	437.59	425.11	-2.85%	422.76	425.88	0.74%
	3	Clear Sky wo/Hg	0.48	414.3	417.2	2.9	0.70%	424.2	420.2	-4.0	-0.95%	409.9	415.9	6.1	1.48%	414.31	409.85	-1.08%	417.22	415.91	-0.31%
		NAAQS	0.48	418.7	422.0	3.3	0.80%	424.8	429.2	4.4	1.03%	418.8	415.4	-3.3	-0.80%	418.66	418.77	0.03%	422.00	415.43	-1.56%
		Utility Based (Coal)	0.48	421.4	421.8	0.4	0.09%	413.8	416.0	2.2	0.53%	413.2	407.3	-5.9	-1.42%	421.39	413.16	-1.95%	421.78	407.27	-3.44%
		Utility Based High	0.48	421.4	421.8	0.4	0.09%	408.3	409.6	1.2	0.30%	411.6	404.3	-7.3	-1.77%	421.39	411.64	-2.31%	421.78	404.34	-4.14%
	P(l)	Clear Sky w/Hg	0.49	723.2	703.8	-19.4	-2.68%	652.5	653.5	1.0	0.15%	655.9	645.1	-10.8	-1.65%	723.18	655.91	-9.30%	703.83	645.10	-8.34%
	4	Clear Sky wo/Hg	0.49	638.8	658.8	20.0	3.13%	614.7	631.8	17.2	2.79%	610.0	618.3	8.3	1.36%	638.83	609.97	-4.62%	658.82	618.27	-6.16%
		NAAQS	0.49	686.3	690.5	4.2	0.62%	608.3	607.1	-1.2	-0.19%	580.2	563.3	-16.9	-2.91%	686.26	580.20	-15.45%	690.50	563.33	-18.42%
		Utility Based (Coal)	0.49	667.5	646.8	-20.7	-3.10%	656.1	646.2	-9.9	-1.50%	609.8	604.0	-5.9	-0.96%	667.47	609.82	-8.64%	646.75	603.95	-6.62%
		Utility Based High	0.49	667.5	646.8	-20.7	-3.10%	637.0	637.3	0.4	0.06%	608.9	598.8	-10.1	-1.66%	667.47	608.90	-8.77%	646.75	598.81	-7.41%
	FD(l)	Clear Sky w/Hg	0.49	713.0	688.7	-24.3	-3.41%	635.9	641.9	6.0	0.95%	647.8	639.4	-8.4	-1.30%	713.00	647.80	-9.14%	688.66	639.40	-7.15%
	6	Clear Sky wo/Hg	0.49	633.5	653.2	19.7	3.11%	634.6	643.5	8.9	1.40%	603.1	609.0	5.9	0.98%	633.47	603.10	-4.80%	653.17	608.98	-6.77%
		NAAQS	0.49	666.5	650.5	-16.0	-2.40%	611.6	597.6	-14.0	-2.29%	564.3	541.7	-22.7	-4.02%	666.50	564.35	-15.31%	650.48	541.66	-16.73%
		Utility Based (Coal)	0.49	679.6	623.9	-55.6	-8.19%	631.8	623.1	-8.7	-1.37%	581.0	574.5	-6.6	-1.13%	679.56	581.03	-14.50%	623.93	574.46	-7.93%
		Utility Based High	0.49	679.6	623.9	-55.6	-8.19%	595.4	604.8	9.4	1.58%	579.4	568.4	-11.0	-1.89%	679.56	579.37	-14.74%	623.93	568.39	-8.90%
	S(s)	Clear Sky w/Hg	0.77	402.5	410.6	8.2	2.03%	385.3	387.0	1.7	0.44%	380.0	381.9	2.0	0.52%	402.48	379.96	-5.60%	410.65	381.95	-6.98%
	7	Clear Sky wo/Hg	0.77	373.0	382.1	9.1	2.44%	380.0	383.5	3.5	0.93%	364.3	369.6	5.3	1.47%	372.99	364.29	-2.33%	382.08	369.63	-3.26%
		NAAQS	0.77	380.5	385.5	5.0	1.32%	379.2	382.9	3.7	0.97%	381.8	373.4	-8.4	-2.21%	380.49	381.83	0.35%	385.52	373.38	-3.15%
		Utility Based (Coal)	0.77	383.8	381.1	-2.7	-0.71%	371.5	378.6	7.1	1.91%	375.5	365.1	-10.4	-2.76%	383.84	375.46	-2.18%	381.12	365.10	-4.20%
		Utility Based High	0.77	383.8	381.1	-2.7	-0.71%	366.9	373.2	6.3	1.72%	365.8	368.0	2.2	0.61%	383.84	365.79	-4.70%	381.12	368.01	-3.44%
	S(l)	Clear Sky w/Hg	0.49	731.9	714.3	-17.7	-2.42%	689.0	688.7	-0.3	-0.05%	680.2	688.1	7.9	1.15%	731.95	680.25	-7.06%	714.26	688.10	-3.66%
	8	Clear Sky wo/Hg	0.49	679.0	669.9	-9.2	-1.35%	643.7	656.6	12.9	2.00%	620.4	628.8	8.4	1.35%	679.04	620.42	-8.63%	669.85	628.79	-6.19%
		NAAQS	0.49	710.6	713.5	2.8	0.40%	637.2	633.7	-3.4	-0.54%	606.4	593.4	-13.0	-2.15%	710.65	606.42	-14.67%	713.46	593.37	-16.83%
		Utility Based (Coal)	0.49	703.6	701.8	-1.8	-0.26%	677.0	661.8	-15.2	-2.24%	638.8	629.0	-9.8	-1.53%	703.60	638.79	-9.21%	701.78	629.01	-10.37%
		Utility Based High	0.49	703.6	701.8	-1.8	-0.26%	648.6	656.1	7.5	1.16%	643.5	620.7	-22.8	-3.54%	703.60	643.52	-8.54%	701.78	620.73	-11.55%
	SB(s)	Clear Sky w/Hg	2.07	15.1	14.7	-0.4	-2.70%	11.7	11.7	0.0	0.35%	11.2	11.2	0.0	-0.02%	15.09	11.18	-25.87%	14.68	11.18	-23.83%
	14	Clear Sky wo/Hg	2.07	10.8	11.5	0.7	6.89%	11.8	11.6	-0.2	-1.41%	9.0	9.4	0.4	4.19%	10.75	8.97	-16.55%	11.50	9.35	-18.66%
		NAAQS	2.07	14.4	14.5	0.2	1.05%	9.5	9.6	0.1	1.45%	8.3	8.2	-0.1	-1.72%	14.36	8.34	-41.92%	14.52	8.20	-43.51%
		Utility Based (Coal)	2.07	12.4	12.4	0.1	0.66%	11.1	10.8	-0.3	-2.99%	10.0	9.3	-0.7	-6.81%	12.35	9.96	-19.34%	12.44	9.31	-25.17%
		Utility Based High	2.07	12.4	12.4	0.1	0.66%	11.0	11.4	0.4	3.26%	8.6	8.8	0.1	1.74%	12.35	8.60	-30.37%	12.44	8.75	-29.62%

TABLE 9
Montgomery Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Montgomery	ES(s)	Clear Sky w/Hg	3.65	1242.5	1233.3	-9.2	-0.74%	1220.3	1222.5	2.2	0.18%	1233.1	1225.0	-8.2	-0.66%	1242.47	1233.15	-0.75%	1233.30	1224.96	-0.68%
	1	Clear Sky wo/Hg	3.65	1230.5	1235.3	4.8	0.39%	1199.3	1195.6	-3.8	-0.31%	1211.4	1207.8	-3.6	-0.30%	1230.55	1211.38	-1.56%	1235.30	1207.78	-2.23%
		NAAQS	3.65	1233.7	1231.0	-2.8	-0.22%	1196.9	1196.9	0.0	0.00%	1200.6	1184.8	-15.8	-1.31%	1233.75	1200.62	-2.69%	1231.00	1184.83	-3.75%
		Utility Based (Coal)	3.65	1235.5	1205.8	-29.7	-2.40%	1193.5	1205.4	11.9	0.99%	1180.4	1173.0	-7.5	-0.63%	1235.49	1180.43	-4.46%	1205.77	1172.97	-2.72%
		Utility Based High	3.65	1235.5	1205.8	-29.7	-2.40%	1184.7	1183.6	-1.1	-0.09%	1179.1	1165.9	-13.2	-1.12%	1235.49	1179.12	-4.56%	1205.77	1165.92	-3.30%
	ES(f)	Clear Sky w/Hg	4.36	856.7	844.6	-12.0	-1.40%	807.3	808.1	0.8	0.10%	828.3	820.7	-7.6	-0.92%	856.65	828.27	-3.31%	844.62	820.68	-2.83%
	2	Clear Sky wo/Hg	4.36	808.0	819.5	11.5	1.43%	809.1	804.7	-4.4	-0.54%	782.1	788.7	6.6	0.85%	808.00	782.11	-3.21%	819.52	788.73	-3.76%
		NAAQS	4.36	838.8	823.3	-15.5	-1.84%	794.3	790.7	-3.6	-0.46%	771.5	758.1	-13.5	-1.75%	838.77	771.53	-8.02%	823.30	758.05	-7.93%
		Utility Based (Coal)	4.36	851.3	810.8	-40.5	-4.76%	823.2	821.7	-1.5	-0.19%	790.9	786.7	-4.2	-0.53%	851.31	790.93	-7.09%	810.80	786.74	-2.97%
		Utility Based High	4.36	851.3	810.8	-40.5	-4.76%	793.6	800.7	7.1	0.90%	783.8	774.3	-9.4	-1.20%	851.31	783.75	-7.94%	810.80	774.34	-4.50%
	P(s)	Clear Sky w/Hg	1.55	1556.7	1516.2	-40.6	-2.61%	1521.7	1516.9	-4.8	-0.31%	1522.9	1526.9	4.0	0.26%	1556.71	1522.87	-2.17%	1516.15	1526.85	0.71%
	3	Clear Sky wo/Hg	1.55	1498.2	1504.7	6.5	0.43%	1510.4	1498.0	-12.4	-0.82%	1480.4	1489.5	9.2	0.62%	1498.20	1480.37	-1.19%	1504.68	1489.56	-1.01%
		NAAQS	1.55	1508.2	1510.1	1.9	0.13%	1513.1	1519.9	6.7	0.44%	1506.8	1485.4	-21.4	-1.42%	1508.17	1506.85	-0.09%	1510.07	1485.42	-1.63%
		Utility Based (Coal)	1.55	1515.1	1505.6	-9.4	-0.62%	1499.8	1502.3	2.5	0.17%	1489.1	1473.4	-15.7	-1.06%	1515.06	1489.12	-1.71%	1505.63	1473.39	-2.14%
		Utility Based High	1.55	1515.1	1505.6	-9.4	-0.62%	1493.7	1487.1	-6.6	-0.44%	1476.2	1467.4	-8.8	-0.60%	1515.06	1476.19	-2.57%	1505.63	1467.37	-2.54%
	P(l)	Clear Sky w/Hg	1.53	2395.2	2383.8	-11.4	-0.48%	2217.3	2213.8	-3.5	-0.16%	2255.2	2237.3	-17.9	-0.80%	2395.20	2255.23	-5.84%	2383.80	2237.29	-6.15%
	4	Clear Sky wo/Hg	1.53	2204.0	2254.5	50.5	2.29%	2149.9	2170.5	20.6	0.96%	2095.8	2126.3	30.5	1.46%	2204.01	2095.80	-4.91%	2254.54	2126.30	-5.69%
		NAAQS	1.53	2327.5	2335.4	7.8	0.34%	2098.9	2119.0	20.1	0.96%	2058.0	2018.0	-40.0	-1.94%	2327.55	2057.98	-11.58%	2335.38	2018.00	-13.58%
		Utility Based (Coal)	1.53	2309.0	2207.8	-101.1	-4.38%	2282.2	2259.5	-22.6	-0.99%	2161.5	2127.2	-34.3	-1.59%	2308.99	2161.52	-6.39%	2207.84	2127.24	-3.65%
		Utility Based High	1.53	2309.0	2207.8	-101.1	-4.38%	2226.3	2227.2	0.9	0.04%	2138.8	2111.8	-27.0	-1.26%	2308.99	2138.80	-7.37%	2207.84	2111.77	-4.35%
	FD(l)	Clear Sky w/Hg	1.53	2395.6	2343.3	-52.3	-2.18%	2208.4	2214.7	6.2	0.28%	2251.3	2228.3	-23.0	-1.02%	2395.58	2251.26	-6.02%	2343.30	2228.29	-4.91%
	6	Clear Sky wo/Hg	1.53	2186.1	2229.0	42.9	1.96%	2198.8	2202.9	4.1	0.19%	2058.3	2106.6	48.4	2.35%	2186.11	2058.28	-5.85%	2229.00	2106.63	-5.48%
		NAAQS	1.53	2304.5	2236.0	-68.5	-2.97%	2130.4	2116.2	-14.2	-0.67%	2023.3	2000.8	-22.5	-1.11%	2304.51	2023.33	-12.20%	2235.99	2000.84	-10.52%
		Utility Based (Coal)	1.53	2374.4	2204.1	-170.3	-7.17%	2228.4	2225.1	-3.3	-0.15%	2102.6	2063.9	-38.7	-1.84%	2374.35	2102.61	-11.44%	2204.07	2063.88	-6.36%
		Utility Based High	1.53	2374.4	2204.1	-170.3	-7.17%	2117.6	2154.7	37.1	1.75%	2093.1	2041.9	-51.2	-2.45%	2374.35	2093.12	-11.84%	2204.07	2041.90	-7.36%
	S(s)	Clear Sky w/Hg	2.36	1418.7	1405.3	-13.5	-0.95%	1339.2	1340.6	1.3	0.10%	1340.7	1344.2	3.5	0.26%	1418.71	1340.66	-5.50%	1405.26	1344.18	-4.35%
	7	Clear Sky wo/Hg	2.36	1315.1	1347.6	32.5	2.47%	1320.0	1332.7	12.7	0.97%	1276.6	1286.0	9.4	0.73%	1315.13	1276.64	-2.93%	1347.59	1285.99	-4.57%
		NAAQS	2.36	1345.5	1349.3	3.7	0.28%	1316.5	1325.2	8.6	0.65%	1337.1	1318.4	-18.7	-1.40%	1345.53	1337.09	-0.63%	1349.28	1318.37	-2.29%
		Utility Based (Coal)	2.36	1364.4	1340.9	-23.5	-1.72%	1320.0	1334.8	14.8	1.12%	1332.3	1303.8	-28.5	-2.14%	1364.36	1332.28	-2.35%	1340.88	1303.82	-2.76%
		Utility Based High	2.36	1364.4	1340.9	-23.5	-1.72%	1317.8	1331.0	13.2	1.00%	1300.9	1308.3	7.4	0.57%	1364.36	1300.91	-4.65%	1340.88	1308.32	-2.43%
	S(l)	Clear Sky w/Hg	1.52	2453.2	2391.4	-61.8	-2.52%	2297.7	2293.9	-3.8	-0.17%	2299.3	2328.0	28.8	1.25%	2453.16	2299.25	-6.27%	2391.36	2328.05	-2.65%
	8	Clear Sky wo/Hg	1.52	2297.9	2290.4	-7.4	-0.32%	2220.7	2224.9	4.3	0.19%	2125.1	2139.0	13.9	0.65%	2297.88	2125.08	-7.52%	2290.43	2138.99	-6.61%
		NAAQS	1.52	2368.8	2390.1	21.3	0.90%	2180.0	2166.7	-13.4	-0.61%	2117.9	2081.5	-36.4	-1.72%	2368.78	2117.88	-10.59%	2390.10	2081.50	-12.91%
		Utility Based (Coal)	1.52	2358.1	2359.9	1.8	0.08%	2319.2	2301.3	-17.9	-0.77%	2219.0	2184.0	-35.0	-1.58%	2358.11	2219.01	-5.90%	2359.89	2183.96	-7.45%
		Utility Based High	1.52	2358.1	2359.9	1.8	0.08%	2234.2	2279.3	45.1	2.02%	2230.3	2165.5	-64.8	-2.91%	2358.11	2230.30	-5.42%	2359.89	2165.45	-8.24%
	SB(s)	Clear Sky w/Hg	5.25	74.1	78.5	4.4	5.91%	68.6	68.9	0.3	0.37%	67.8	69.0	1.2	1.81%	74.11	67.82	-8.49%	78.49	69.05	-12.03%
	14	Clear Sky wo/Hg	5.25	65.2	65.6	0.4	0.59%	64.7	62.0	-2.7	-4.21%	58.8	59.2	0.4	0.69%	65.22	58.83	-9.79%	65.60	59.24	-9.70%
		NAAQS	5.25	75.8	74.1	-1.6	-2.15%	59.9	60.6	0.7	1.24%	57.7	55.3	-2.4	-4.12%	75.78	57.71	-23.84%	74.15	55.33	-25.38%
		Utility Based (Coal)	5.25	68.7	68.1	-0.6	-0.85%	68.0	67.3	-0.6	-0.95%	63.0	59.9	-3.0	-4.83%	68.70	62.96	-8.36%	68.11	59.92	-12.03%
		Utility Based High	5.25	68.7	68.1	-0.6	-0.85%	66.0	66.5	0.4	0.67%	58.4	57.9	-0.4	-0.76%	68.70	58.36	-15.05%	68.11	57.92	-14.97%

TABLE 10
New Cumberland Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
New Cumberland	ES(s)	Clear Sky w/Hg	3.84	1222.8	1213.1	-9.7	-0.79%	1180.2	1183.7	3.5	0.30%	1179.4	1178.2	-1.2	-0.10%	1222.78	1179.37	-3.55%	1213.12	1178.19	-2.88%
	1	Clear Sky wo/Hg	3.84	1168.9	1173.6	4.7	0.40%	1166.0	1165.2	-0.8	-0.07%	1150.1	1153.5	3.4	0.29%	1168.87	1150.11	-1.61%	1173.59	1153.48	-1.71%
		NAAQS	3.84	1197.5	1186.8	-10.7	-0.89%	1157.9	1159.0	1.1	0.09%	1142.2	1142.8	0.6	0.05%	1197.50	1142.21	-4.62%	1186.82	1142.78	-3.71%
		Utility Based (Coal)	3.84	1220.4	1175.7	-44.8	-3.67%	1177.4	1179.7	2.3	0.19%	1157.7	1156.2	-1.5	-0.13%	1220.45	1157.71	-5.14%	1175.65	1156.17	-1.66%
		Utility Based High	3.84	1220.4	1175.7	-44.8	-3.67%	1158.1	1157.1	-0.9	-0.08%	1149.1	1138.2	-10.9	-0.95%	1220.45	1149.11	-5.84%	1175.65	1138.24	-3.18%
	ES(f)	Clear Sky w/Hg	6.16	1315.1	1306.9	-8.2	-0.62%	1250.9	1256.0	5.0	0.40%	1245.3	1240.4	-4.9	-0.39%	1315.07	1245.27	-5.31%	1306.91	1240.37	-5.09%
	2	Clear Sky wo/Hg	6.16	1237.5	1259.4	22.0	1.77%	1245.2	1221.3	-23.9	-1.92%	1193.9	1201.2	7.2	0.61%	1237.47	1193.93	-3.52%	1259.43	1201.17	-4.63%
		NAAQS	6.16	1291.7	1267.7	-24.1	-1.86%	1208.4	1208.9	0.5	0.04%	1191.8	1174.3	-17.5	-1.47%	1291.72	1191.78	-7.74%	1267.67	1174.27	-7.37%
		Utility Based (Coal)	6.16	1304.3	1245.4	-58.9	-4.51%	1226.2	1236.3	10.1	0.83%	1189.7	1198.4	8.7	0.73%	1304.32	1189.67	-8.79%	1245.44	1198.37	-3.78%
		Utility Based High	6.16	1304.3	1245.4	-58.9	-4.51%	1211.7	1216.6	4.9	0.41%	1170.3	1177.3	7.1	0.60%	1304.32	1170.27	-10.28%	1245.44	1177.34	-5.47%
	P(s)	Clear Sky w/Hg	1.82	1368.5	1340.8	-27.7	-2.02%	1304.0	1302.0	-2.0	-0.15%	1305.1	1304.0	-1.1	-0.09%	1368.51	1305.11	-4.63%	1340.81	1303.96	-2.75%
	3	Clear Sky wo/Hg	1.82	1300.5	1299.5	-1.0	-0.08%	1298.2	1285.2	-13.0	-1.00%	1276.7	1284.6	7.8	0.61%	1300.52	1276.71	-1.83%	1299.50	1284.55	-1.15%
		NAAQS	1.82	1304.0	1307.2	3.2	0.25%	1293.6	1296.2	2.6	0.20%	1284.7	1284.2	-0.4	-0.03%	1304.00	1284.66	-1.48%	1307.24	1284.24	-1.76%
		Utility Based (Coal)	1.82	1309.0	1307.8	-1.2	-0.09%	1292.4	1295.8	3.3	0.26%	1279.8	1277.3	-2.6	-0.20%	1309.02	1279.83	-2.23%	1307.82	1277.26	-2.34%
		Utility Based High	1.82	1309.0	1307.8	-1.2	-0.09%	1286.8	1293.1	6.3	0.49%	1278.5	1275.8	-2.7	-0.21%	1309.02	1278.54	-2.33%	1307.82	1275.83	-2.45%
	P(l)	Clear Sky w/Hg	2.38	3174.8	3176.9	2.1	0.06%	2978.1	2983.1	5.1	0.17%	2935.7	2943.0	7.2	0.25%	3174.84	2935.73	-7.53%	3176.89	2942.96	-7.36%
	4	Clear Sky wo/Hg	2.38	2929.1	2970.1	41.0	1.40%	2822.1	2841.0	18.9	0.67%	2802.8	2829.5	26.7	0.95%	2929.14	2802.79	-4.31%	2970.10	2829.52	-4.73%
		NAAQS	2.38	3061.3	3051.1	-10.2	-0.33%	2824.5	2839.5	15.0	0.53%	2751.5	2736.6	-14.9	-0.54%	3061.29	2751.49	-10.12%	3051.12	2736.64	-10.31%
		Utility Based (Coal)	2.38	3045.3	2962.3	-83.0	-2.73%	2916.2	2914.5	-1.7	-0.06%	2820.1	2816.5	-3.6	-0.13%	3045.32	2820.11	-7.40%	2962.29	2816.54	-4.92%
		Utility Based High	2.38	3045.3	2962.3	-83.0	-2.73%	2902.9	2896.1	-6.8	-0.23%	2776.2	2739.1	-37.1	-1.34%	3045.32	2776.16	-8.84%	2962.29	2739.06	-7.54%
	FD(l)	Clear Sky w/Hg	2.37	3170.2	3133.5	-36.7	-1.16%	2947.7	2960.4	12.7	0.43%	2873.3	2875.4	2.2	0.08%	3170.24	2873.27	-9.37%	3133.53	2875.45	-8.24%
	6	Clear Sky wo/Hg	2.37	2872.6	2953.6	81.1	2.82%	2899.2	2863.0	-36.2	-1.25%	2727.9	2732.6	4.7	0.17%	2872.57	2727.90	-5.04%	2953.64	2732.62	-7.48%
		NAAQS	2.37	3060.3	2982.8	-77.5	-2.53%	2791.9	2794.3	2.4	0.09%	2732.4	2696.2	-36.2	-1.32%	3060.31	2732.39	-10.72%	2982.76	2696.20	-9.61%
		Utility Based (Coal)	2.37	3119.1	2921.3	-197.8	-6.34%	2829.0	2888.2	59.2	2.09%	2732.9	2710.0	-22.9	-0.84%	3119.07	2732.87	-12.36%	2921.28	2709.96	-7.23%
		Utility Based High	2.37	3119.1	2921.3	-197.8	-6.34%	2809.3	2836.2	26.9	0.96%	2678.8	2636.1	-42.7	-1.59%	3119.07	2678.77	-14.12%	2921.28	2636.06	-9.76%
	S(s)	Clear Sky w/Hg	2.38	1206.2	1206.9	0.6	0.05%	1128.9	1127.9	-1.0	-0.09%	1143.7	1140.6	-3.1	-0.27%	1206.23	1143.74	-5.18%	1206.86	1140.61	-5.49%
	7	Clear Sky wo/Hg	2.38	1132.2	1136.3	4.1	0.36%	1121.9	1129.9	8.0	0.71%	1092.1	1097.3	5.2	0.47%	1132.21	1092.11	-3.54%	1136.30	1097.28	-3.43%
		NAAQS	2.38	1139.1	1154.6	15.5	1.36%	1115.4	1120.7	5.2	0.47%	1124.2	1113.6	-10.7	-0.95%	1139.07	1124.25	-1.30%	1154.60	1113.58	-3.55%
		Utility Based (Coal)	2.38	1155.3	1145.7	-9.5	-0.82%	1127.6	1140.0	12.4	1.10%	1116.6	1114.1	-2.5	-0.22%	1155.28	1116.64	-3.34%	1145.75	1114.15	-2.76%
		Utility Based High	2.38	1155.3	1145.7	-9.5	-0.82%	1111.6	1127.3	15.8	1.42%	1114.8	1114.2	-0.7	-0.06%	1155.28	1114.83	-3.50%	1145.75	1114.17	-2.76%
	S(l)	Clear Sky w/Hg	2.36	3239.2	3197.1	-42.1	-1.30%	3027.3	3014.9	-12.4	-0.41%	2954.2	3010.6	56.4	1.91%	3239.18	2954.22	-8.80%	3197.08	3010.59	-5.83%
	8	Clear Sky wo/Hg	2.36	3018.5	2990.2	-28.3	-0.94%	2910.7	2902.3	-8.4	-0.29%	2831.4	2835.1	3.7	0.13%	3018.47	2831.43	-6.20%	2990.21	2835.14	-5.19%
		NAAQS	2.36	3043.4	3095.9	52.5	1.73%	2866.9	2845.5	-21.4	-0.75%	2833.2	2816.9	-16.3	-0.57%	3043.36	2833.17	-6.91%	3095.86	2816.91	-9.01%
		Utility Based (Coal)	2.36	3025.2	3010.6	-14.6	-0.48%	2983.0	3015.9	32.9	1.10%	2884.9	2860.6	-24.4	-0.84%	3025.25	2884.93	-4.64%	3010.63	2860.56	-4.95%
		Utility Based High	2.36	3025.2	3010.6	-14.6	-0.48%	2909.8	2943.1	33.3	1.14%	2923.2	2815.1	-108.1	-3.70%	3025.25	2923.21	-3.37%	3010.63	2815.10	-6.49%
	SB(s)	Clear Sky w/Hg	7.51	112.5	111.1	-1.4	-1.26%	93.1	92.8	-0.3	-0.37%	97.5	99.0	1.5	1.56%	112.52	97.48	-13.37%	111.11	98.99	-10.90%
	14	Clear Sky wo/Hg	7.51	89.4	90.5	1.1	1.20%	80.9	82.3	1.4	1.73%	74.3	75.2	0.9	1.17%	89.44	74.34	-16.88%	90.51	75.21	-16.90%
		NAAQS	7.51	102.4	100.5	-2.0	-1.91%	78.8	80.5	1.7	2.11%	78.0	74.4	-3.7	-4.88%	102.44	78.04	-23.82%	100.48	74.38	-25.97%
		Utility Based (Coal)	7.51	99.7	96.8	-2.9	-2.86%	91.8	91.2	-0.6	-0.65%	87.9	82.7	-5.2	-5.92%	99.67	87.94	-11.76%	96.82	82.73	-14.55%
		Utility Based High	7.51	99.7	96.8	-2.9	-2.86%	88.4	88.7	0.4	0.41%	76.1	79.4	3.3	4.35%	99.67	76.10	-23.65%	96.82	79.41	-17.96%

[1]ES(s)=Emerald Shiner (spawning); ES(f)=Emerald Shiner (fry); P(s)=Paddlefish (spawning); P(l)=Paddlefish (larval); FD(l)=Freshwater Drum (larval); S(s)=Sauger (spawning); S(l)=Sauger (larval); SB(s)=Spotted Bass (spawning)

TABLE 11
Pike Island
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Pike Island	ES(s)	Clear Sky w/Hg	3.84	1253.5	1238.0	-15.5	-1.24%	1204.0	1205.0	1.0	0.09%	1199.1	1195.3	-3.8	-0.31%	1253.50	1199.06	-4.34%	1237.98	1195.31	-3.45%
	1	Clear Sky wo/Hg	3.84	1165.9	1175.3	9.4	0.81%	1178.5	1180.3	1.8	0.15%	1170.2	1170.0	-0.2	-0.02%	1165.87	1170.25	0.38%	1175.27	1170.01	-0.45%
		NAAQS	3.84	1206.5	1196.4	-10.1	-0.84%	1167.4	1168.0	0.6	0.06%	1155.8	1156.1	0.3	0.03%	1206.55	1155.78	-4.21%	1196.44	1156.10	-3.37%
		Utility Based (Coal)	3.84	1221.9	1182.9	-39.0	-3.19%	1182.0	1181.5	-0.5	-0.04%	1160.3	1159.6	-0.7	-0.06%	1221.87	1160.33	-5.04%	1182.85	1159.59	-1.97%
		Utility Based High	3.84	1221.9	1182.9	-39.0	-3.19%	1171.0	1177.4	6.5	0.55%	1154.4	1148.1	-6.3	-0.55%	1221.87	1154.44	-5.52%	1182.85	1148.14	-2.93%
	ES(f)	Clear Sky w/Hg	6.16	1165.6	1159.1	-6.5	-0.56%	1115.5	1117.5	2.0	0.18%	1087.4	1091.3	3.9	0.36%	1165.62	1087.36	-6.71%	1159.15	1091.27	-5.86%
	2	Clear Sky wo/Hg	6.16	1081.1	1109.2	28.0	2.59%	1100.0	1087.8	-12.2	-1.11%	1060.8	1056.6	-4.2	-0.39%	1081.13	1060.77	-1.88%	1109.16	1056.60	-4.74%
		NAAQS	6.16	1132.5	1121.8	-10.7	-0.95%	1078.7	1075.0	-3.7	-0.35%	1065.5	1047.1	-18.3	-1.72%	1132.50	1065.48	-5.92%	1121.75	1047.14	-6.66%
		Utility Based (Coal)	6.16	1165.7	1110.6	-55.0	-4.72%	1098.3	1095.7	-2.6	-0.24%	1058.1	1062.0	3.9	0.37%	1165.65	1058.11	-9.23%	1110.61	1062.00	-4.36%
		Utility Based High	6.16	1165.7	1110.6	-55.0	-4.72%	1079.0	1080.6	1.6	0.15%	1039.6	1050.5	10.9	1.05%	1165.65	1039.60	-10.81%	1110.61	1050.54	-5.41%
	P(s)	Clear Sky w/Hg	1.82	1656.6	1619.3	-37.3	-2.25%	1571.2	1561.5	-9.7	-0.61%	1580.2	1574.6	-5.6	-0.35%	1656.64	1580.21	-4.61%	1619.31	1574.62	-2.76%
	3	Clear Sky wo/Hg	1.82	1545.2	1547.6	2.3	0.15%	1556.3	1535.1	-21.3	-1.37%	1529.8	1542.6	12.8	0.84%	1545.21	1529.78	-1.00%	1547.55	1542.58	-0.32%
		NAAQS	1.82	1566.9	1561.3	-5.6	-0.36%	1558.7	1556.9	-1.7	-0.11%	1545.8	1550.9	5.1	0.33%	1566.92	1545.82	-1.35%	1561.29	1550.88	-0.67%
		Utility Based (Coal)	1.82	1563.8	1565.9	2.1	0.14%	1537.9	1548.1	10.1	0.66%	1530.2	1527.4	-2.8	-0.18%	1563.76	1530.22	-2.15%	1565.88	1527.41	-2.46%
		Utility Based High	1.82	1563.8	1565.9	2.1	0.14%	1529.7	1540.4	10.7	0.70%	1500.9	1500.9	0.0	0.00%	1563.76	1500.87	-4.02%	1565.88	1500.90	-4.15%
	P(i)	Clear Sky w/Hg	2.38	3583.9	3548.0	-35.9	-1.00%	3344.5	3357.3	12.7	0.38%	3186.4	3222.3	35.9	1.13%	3583.88	3186.37	-11.09%	3547.99	3222.31	-9.18%
	4	Clear Sky wo/Hg	2.38	3242.3	3287.2	44.8	1.38%	3132.0	3170.5	38.5	1.23%	3131.4	3148.7	17.3	0.55%	3242.34	3131.37	-3.42%	3287.16	3148.67	-4.21%
		NAAQS	2.38	3421.7	3384.7	-37.0	-1.08%	3150.1	3163.0	13.0	0.41%	3058.1	3043.1	-15.0	-0.49%	3421.66	3058.14	-10.62%	3384.67	3043.14	-10.09%
		Utility Based (Coal)	2.38	3466.3	3333.1	-133.2	-3.84%	3257.3	3297.6	40.3	1.24%	3129.7	3123.7	-6.0	-0.19%	3466.29	3129.73	-9.71%	3333.10	3123.69	-6.28%
		Utility Based High	2.38	3466.3	3333.1	-133.2	-3.84%	3235.1	3221.1	-14.0	-0.43%	3067.0	3032.4	-34.7	-1.13%	3466.29	3067.05	-11.52%	3333.10	3032.38	-9.02%
	FD(i)	Clear Sky w/Hg	2.37	3533.2	3486.0	-47.2	-1.34%	3275.3	3282.7	7.4	0.23%	3119.7	3144.7	25.0	0.80%	3533.17	3119.67	-11.70%	3485.97	3144.71	-9.79%
	6	Clear Sky wo/Hg	2.37	3104.7	3217.8	113.2	3.64%	3166.0	3171.4	-14.6	-0.46%	3000.7	2964.8	-35.9	-1.20%	3104.67	3000.69	-3.35%	3217.82	2964.81	-7.86%
		NAAQS	2.37	3331.3	3282.7	-48.7	-1.46%	3106.0	3088.2	-17.8	-0.57%	3040.3	2962.7	-77.6	-2.55%	3331.35	3040.31	-8.74%	3282.68	2962.68	-9.75%
		Utility Based (Coal)	2.37	3503.2	3245.3	-257.9	-7.36%	3163.2	3175.1	11.9	0.38%	3006.1	2968.9	-37.2	-1.24%	3503.22	3006.10	-14.18%	3245.29	2968.87	-8.52%
		Utility Based High	2.37	3503.2	3245.3	-257.9	-7.36%	3122.6	3144.5	22.0	0.70%	2920.7	2913.1	-7.6	-0.26%	3503.22	2920.73	-16.63%	3245.29	2913.09	-10.24%
	S(s)	Clear Sky w/Hg	2.38	1291.5	1288.7	-2.9	-0.22%	1207.0	1202.1	-4.9	-0.41%	1235.2	1230.3	-4.9	-0.39%	1291.55	1235.16	-4.37%	1288.66	1230.30	-4.53%
	7	Clear Sky wo/Hg	2.38	1191.9	1206.1	14.1	1.19%	1181.4	1172.8	-8.5	-0.72%	1157.0	1175.8	18.8	1.62%	1191.94	1157.05	-2.93%	1206.06	1175.83	-2.61%
		NAAQS	2.38	1200.6	1199.2	-1.4	-0.11%	1185.8	1190.2	4.3	0.37%	1201.8	1176.3	-25.5	-2.13%	1200.59	1201.84	0.10%	1199.23	1176.30	-1.91%
		Utility Based (Coal)	2.38	1213.5	1223.5	10.0	0.82%	1198.7	1208.1	9.4	0.79%	1188.4	1180.6	-7.8	-0.65%	1213.55	1188.38	-2.07%	1223.50	1180.60	-3.51%
		Utility Based High	2.38	1213.5	1223.5	10.0	0.82%	1166.9	1199.4	32.5	2.79%	1162.2	1156.1	-6.0	-0.52%	1213.55	1162.15	-4.23%	1223.50	1156.14	-5.51%
	S(i)	Clear Sky w/Hg	2.36	3656.6	3618.9	-37.7	-1.03%	3409.0	3396.8	-12.2	-0.36%	3317.2	3365.7	48.5	1.46%	3656.64	3317.16	-9.28%	3618.90	3365.69	-7.00%
	8	Clear Sky wo/Hg	2.36	3393.5	3344.8	-48.7	-1.43%	3275.0	3263.4	-11.5	-0.35%	3158.4	3179.4	21.0	0.67%	3393.49	3158.39	-6.93%	3344.83	3179.42	-4.95%
		NAAQS	2.36	3447.2	3448.8	1.6	0.05%	3260.2	3257.2	-3.1	-0.09%	3175.8	3167.4	-8.5	-0.27%	3447.22	3175.83	-7.87%	3448.82	3167.35	-8.18%
		Utility Based (Coal)	2.36	3454.0	3454.6	0.6	0.02%	3395.6	3438.9	43.3	1.27%	3226.1	3211.5	-14.6	-0.45%	3453.98	3226.11	-6.60%	3454.57	3211.48	-7.04%
		Utility Based High	2.36	3454.0	3454.6	0.6	0.02%	3305.4	3366.5	61.1	1.85%	3259.0	3121.8	-137.1	-4.21%	3453.98	3258.96	-5.65%	3454.57	3121.82	-9.63%
	SB(s)	Clear Sky w/Hg	7.51	84.2	81.0	-3.2	-3.77%	74.3	73.3	-1.0	-1.35%	71.2	72.3	1.1	1.57%	84.19	71.15	-15.48%	81.01	72.27	-10.79%
	14	Clear Sky wo/Hg	7.51	69.3	65.6	-3.7	-5.31%	64.3	63.3	-1.0	-1.61%	58.3	57.7	-0.6	-0.98%	69.28	58.29	-15.86%	65.60	57.72	-12.01%
		NAAQS	7.51	71.8	73.2	1.4	1.88%	60.1	61.6	1.5	2.49%	56.4	57.2	0.8	1.39%	71.83	56.40	-21.47%	73.18	57.19	-21.85%
		Utility Based (Coal)	7.51	83.1	78.5	-4.7	-5.61%	69.4	68.9	-0.5	-0.78%	65.7	65.6	-0.1	-0.11%	83.12	65.66	-21.00%	78.46	65.58	-16.41%
		Utility Based High	7.51	83.1	78.5	-4.7	-5.61%	68.7	66.8	-1.9	-2.76%	58.6	62.7	4.1	6.97%	83.12	58.61	-29.48%	78.46	62.70	-20.08%

TABLE 12
Hannibal Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Hannibal	ES(s)	Clear Sky w/Hg	5.11	1694.7	1696.1	1.3	0.08%	1661.7	1665.8	4.2	0.25%	1648.1	1645.2	-2.9	-0.18%	1694.73	1648.14	-2.75%	1696.06	1645.21	-3.00%
	1	Clear Sky wo/Hg	5.11	1634.3	1663.3	29.0	1.78%	1635.6	1634.6	-1.0	-0.06%	1610.4	1619.9	9.5	0.59%	1634.28	1610.39	-1.46%	1663.31	1619.88	-2.61%
		NAAQS	5.11	1670.1	1665.6	-4.5	-0.27%	1619.7	1619.8	0.1	0.01%	1615.7	1625.3	9.6	0.59%	1670.11	1615.66	-3.26%	1665.63	1625.27	-2.42%
		Utility Based (Coal)	5.11	1690.7	1644.6	-46.1	-2.73%	1636.8	1636.7	-0.1	0.00%	1615.6	1621.8	6.1	0.38%	1690.71	1615.65	-4.44%	1644.58	1621.78	-1.39%
		Utility Based High	5.11	1690.7	1644.6	-46.1	-2.73%	1624.3	1624.8	0.5	0.03%	1612.4	1598.7	-13.7	-0.85%	1690.71	1612.39	-4.63%	1644.58	1598.69	-2.79%
	ES(f)	Clear Sky w/Hg	7.74	1449.9	1458.1	8.2	0.56%	1397.1	1399.6	2.5	0.18%	1380.2	1379.1	-1.1	-0.08%	1449.86	1380.22	-4.80%	1458.05	1379.14	-5.41%
	2	Clear Sky wo/Hg	7.74	1379.7	1409.7	30.0	2.17%	1359.2	1356.1	-3.1	-0.23%	1314.8	1307.4	-7.3	-0.56%	1379.74	1314.76	-4.71%	1409.71	1307.41	-7.26%
		NAAQS	7.74	1400.9	1395.6	-5.2	-0.37%	1336.4	1335.0	-1.4	-0.11%	1314.4	1308.3	-6.1	-0.46%	1400.86	1314.36	-6.17%	1395.63	1308.28	-6.26%
		Utility Based (Coal)	7.74	1440.8	1389.0	-51.8	-3.60%	1379.3	1377.6	-1.7	-0.12%	1330.1	1326.3	-3.8	-0.28%	1440.81	1330.07	-7.69%	1388.99	1326.31	-4.51%
		Utility Based High	7.74	1440.8	1389.0	-51.8	-3.60%	1341.8	1335.9	-5.9	-0.44%	1311.8	1307.4	-4.3	-0.33%	1440.81	1311.78	-8.96%	1388.99	1307.44	-5.87%
	P(s)	Clear Sky w/Hg	2.49	2255.7	2217.2	-38.5	-1.71%	2177.3	2175.9	-1.4	-0.06%	2190.3	2188.0	-2.3	-0.11%	2255.72	2190.34	-2.90%	2217.18	2188.01	-1.32%
	3	Clear Sky wo/Hg	2.49	2166.9	2185.6	18.7	0.86%	2163.7	2157.9	-5.8	-0.27%	2139.7	2151.5	11.8	0.55%	2166.91	2139.72	-1.25%	2185.60	2151.48	-1.56%
		NAAQS	2.49	2183.6	2176.6	-7.1	-0.32%	2180.6	2170.2	-10.4	-0.48%	2142.6	2149.8	7.2	0.34%	2183.64	2142.63	-1.88%	2176.59	2149.83	-1.23%
		Utility Based (Coal)	2.49	2176.5	2200.0	23.5	1.08%	2159.5	2155.1	-4.4	-0.20%	2150.1	2147.7	-2.4	-0.11%	2176.47	2150.15	-1.21%	2199.98	2147.72	-2.38%
		Utility Based High	2.49	2176.5	2200.0	23.5	1.08%	2149.1	2151.7	2.6	0.12%	2133.2	2143.7	10.5	0.49%	2176.47	2133.20	-1.99%	2199.98	2143.72	-2.56%
	P(l)	Clear Sky w/Hg	3.15	4522.0	4434.0	-88.0	-1.95%	4219.8	4227.3	7.5	0.18%	4066.4	4095.5	29.0	0.71%	4521.98	4066.45	-10.07%	4433.96	4095.49	-7.63%
	4	Clear Sky wo/Hg	3.15	4073.0	4166.5	93.4	2.29%	3963.7	3981.0	17.3	0.44%	3881.8	3866.0	-15.8	-0.41%	4073.03	3881.76	-4.70%	4166.46	3865.97	-7.21%
		NAAQS	3.15	4219.4	4185.7	-33.7	-0.80%	4012.4	4009.8	-2.6	-0.06%	3845.2	3845.1	-0.2	0.00%	4219.40	3845.22	-8.87%	4185.73	3845.05	-8.14%
		Utility Based (Coal)	3.15	4383.9	4219.1	-164.8	-3.76%	4132.8	4167.7	34.9	0.84%	3957.3	3911.3	-46.0	-1.16%	4383.92	3957.31	-9.73%	4219.15	3911.33	-7.30%
		Utility Based High	3.15	4383.9	4219.1	-164.8	-3.76%	4009.3	3997.5	-11.8	-0.30%	3820.5	3770.4	-50.1	-1.31%	4383.92	3820.50	-12.85%	4219.15	3770.38	-10.64%
	FD(l)	Clear Sky w/Hg	3.15	4431.1	4403.0	-28.1	-0.63%	4115.8	4127.1	11.4	0.28%	3952.2	3957.7	5.5	0.14%	4431.07	3952.19	-10.81%	4402.98	3957.70	-10.11%
	6	Clear Sky wo/Hg	3.15	3978.6	4122.2	143.6	3.61%	3941.1	3962.9	21.8	0.55%	3713.4	3660.9	-52.5	-1.41%	3978.62	3713.42	-6.67%	4122.21	3660.90	-11.19%
		NAAQS	3.15	4114.5	4102.5	-12.1	-0.29%	3856.6	3839.7	-16.9	-0.44%	3746.5	3720.1	-26.4	-0.71%	4114.53	3746.51	-8.94%	4102.47	3720.07	-9.32%
		Utility Based (Coal)	3.15	4342.5	4106.6	-235.9	-5.43%	3987.2	4009.1	21.9	0.55%	3777.8	3726.2	-51.6	-1.36%	4342.52	3777.79	-13.00%	4106.63	3726.24	-9.26%
		Utility Based High	3.15	4342.5	4106.6	-235.9	-5.43%	3867.5	3841.4	-26.1	-0.67%	3656.7	3649.4	-7.2	-0.20%	4342.52	3656.65	-15.79%	4106.63	3649.41	-11.13%
	S(s)	Clear Sky w/Hg	3.03	1566.7	1564.4	-2.3	-0.15%	1510.3	1507.0	-3.3	-0.22%	1511.9	1510.7	-1.3	-0.08%	1566.74	1511.93	-3.50%	1564.41	1510.68	-3.43%
	7	Clear Sky wo/Hg	3.03	1484.7	1504.2	19.5	1.31%	1480.2	1482.0	1.9	0.13%	1456.9	1448.4	-8.5	-0.59%	1484.75	1456.95	-1.87%	1504.23	1448.42	-3.71%
		NAAQS	3.03	1497.4	1500.7	3.2	0.22%	1491.7	1488.5	-3.2	-0.21%	1486.3	1464.0	-22.4	-1.50%	1497.44	1486.34	-0.74%	1500.69	1463.97	-2.45%
		Utility Based (Coal)	3.03	1531.9	1540.5	8.6	0.56%	1504.3	1498.6	-5.7	-0.38%	1472.7	1466.3	-6.3	-0.43%	1531.87	1472.65	-3.87%	1540.50	1466.33	-4.81%
		Utility Based High	3.03	1531.9	1540.5	8.6	0.56%	1453.5	1476.2	22.7	1.56%	1469.5	1477.5	8.0	0.55%	1531.87	1469.51	-4.07%	1540.50	1477.54	-4.09%
	S(l)	Clear Sky w/Hg	3.14	4609.2	4472.4	-136.7	-2.97%	4343.2	4335.5	-7.8	-0.18%	4236.5	4285.6	49.1	1.16%	4609.18	4236.50	-8.09%	4472.44	4285.57	-4.18%
	8	Clear Sky wo/Hg	3.14	4273.0	4244.7	-28.4	-0.66%	4132.2	4102.3	-29.9	-0.72%	3932.7	3961.4	28.7	0.73%	4273.04	3932.67	-7.97%	4244.68	3961.37	-6.67%
		NAAQS	3.14	4265.8	4265.9	0.1	0.00%	4125.5	4101.7	-23.7	-0.58%	3931.2	3924.0	-7.2	-0.18%	4265.80	3931.20	-7.84%	4265.94	3924.04	-8.01%
		Utility Based (Coal)	3.14	4363.8	4395.9	32.1	0.73%	4245.9	4305.3	59.3	1.40%	4058.2	4036.3	-21.8	-0.54%	4363.80	4058.15	-7.00%	4395.87	4036.32	-8.18%
		Utility Based High	3.14	4363.8	4395.9	32.1	0.73%	4144.3	4187.0	42.6	1.03%	3981.4	3926.1	-55.3	-1.39%	4363.80	3981.41	-8.76%	4395.87	3926.14	-10.69%
	SB(s)	Clear Sky w/Hg	8.62	114.9	113.5	-1.5	-1.28%	108.9	110.1	1.2	1.11%	109.2	109.9	0.7	0.64%	114.92	109.20	-4.97%	113.45	109.90	-3.13%
	14	Clear Sky wo/Hg	8.62	108.9	105.0	-3.9	-3.57%	101.7	100.0	-1.7	-1.67%	98.2	97.8	-0.4	-0.38%	108.87	98.22	-9.78%	104.98	97.85	-6.78%
		NAAQS	8.62	105.0	105.2	0.2	0.22%	98.7	100.7	2.0	1.99%	96.4	96.5	0.1	0.13%	105.00	96.38	-8.21%	105.23	96.51	-8.29%
		Utility Based (Coal)	8.62	115.8	112.5	-3.3	-2.84%	105.9	107.4	1.5	1.40%	101.3	100.7	-0.6	-0.58%	115.81	101.27	-12.56%	112.52	100.68	-10.52%
		Utility Based High	8.62	115.8	112.5	-3.3	-2.84%	103.0	103.0	0.0	0.00%	94.9	98.3	3.4	3.58%	115.81	94.87	-18.08%	112.52	98.27	-12.67%

TABLE 13
Willow Island Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010 Without Project HSI Units	2010 With Project HSI Units	2010 Delta	2010 % Delta	2040 Without Project HSI Units	2040 With Project HSI Units	2040 Delta	2040 % Delta	2070 Without Project HSI Units	2070 With Project HSI Units	2070 Delta	2070 % Delta	2010-2070 Without Project 2010	2010-2070 Without Project 2070	2010-2070 % Delta	2010-2070 With Project 2010	2010-2070 With Project 2070	2010-2070 % Delta
Willow Island	ES(s)	Clear Sky w/Hg	5.072029	1377.41273	1377.41273	0.0	0.00%	1363.43827	1371.58883	8.5	0.62%	1326.31173	1329.9217	3.6	0.27%	1377.41	1326.31	-3.71%	1377.41	1328.92	-3.55%
	1	Clear Sky w/Hg	5.072029	1353.8357	1353.8357	0.0	0.00%	1307.80247	1319.18483	11.4	0.87%	1295.7115	1280.40723	-15.3	-1.18%	1353.84	1295.71	-4.29%	1353.84	1280.41	-5.42%
		NAAQS	5.072029	1340.6041	1340.6041	0.0	0.00%	1298.58437	1302.4077	3.8	0.29%	1279.3067	1300.05057	20.7	1.62%	1340.60	1279.31	-4.59%	1340.60	1300.05	-2.96%
		Utility Based (Coal)	5.072029	1329.2633	1329.2633	0.0	0.00%	1328.84947	1335.43123	6.6	0.50%	1305.33603	1292.59863	-12.7	-0.98%	1329.26	1305.34	-1.80%	1329.26	1292.60	-2.76%
		Utility Based High	5.072029	1329.2633	1329.2633	0.0	0.00%	1297.0056	1303.27813	6.3	0.48%	1282.22953	1273.55447	-8.7	-0.66%	1329.26	1282.23	-3.54%	1329.26	1273.55	-4.19%
	ES(f)	Clear Sky w/Hg	7.046262	1232.33353	1248.21357	15.9	1.29%	1196.0941	1203.68173	4.8	0.38%	1170.41833	1172.93343	2.5	0.22%	1232.33	1170.42	-5.02%	1248.21	1172.94	-6.04%
	2	Clear Sky w/Hg	7.046262	1180.78193	1218.94407	38.2	3.37%	1154.07897	1154.5208	0.4	0.04%	1110.9291	1102.2541	-8.7	-0.78%	1180.78	1110.93	-5.92%	1218.94	1102.25	-9.54%
		NAAQS	7.046262	1183.97077	1182.50123	-1.5	-0.12%	1129.7271	1127.77477	-2.0	-0.17%	1102.27207	1096.9512	-5.3	-0.33%	1183.97	1102.27	-6.91%	1182.50	1096.95	-7.25%
		Utility Based (Coal)	7.046262	1240.49127	1183.80923	-56.7	-4.57%	1191.11053	1197.34027	6.2	0.52%	1139.65463	1129.61913	-13.0	-1.14%	1240.49	1139.65	-8.15%	1183.81	1125.92	-4.89%
		Utility Based High	7.046262	1240.49127	1183.80923	-56.7	-4.57%	1146.8485	1147.73453	0.9	0.08%	1110.66907	1107.9998	-2.9	-0.26%	1240.49	1110.67	-10.44%	1183.81	1108.00	-6.38%
	P(a)	Clear Sky w/Hg	2.291487	2037.9545	1996.2375	-41.7	-2.04%	1987.99425	1981.9225	-6.1	-0.31%	1987.508	1968.738	-18.8	-0.94%	2037.95	1987.51	-2.48%	1996.24	1968.73	-1.94%
	3	Clear Sky w/Hg	2.291487	1947.61775	1966.9345	19.3	0.99%	1951.535	1954.3625	2.8	0.14%	1928.47775	1957.74725	29.3	1.52%	1947.62	1928.48	-0.98%	1966.93	1957.75	-0.47%
		NAAQS	2.291487	1969.404	1980.4995	11.1	0.56%	1975.23975	1965.1785	-10.1	-0.51%	1943.168	1943.3795	0.2	0.01%	1969.40	1943.17	-1.33%	1980.50	1943.38	-1.67%
		Utility Based (Coal)	2.291487	1954.55075	1980.65975	26.1	1.34%	1933.7845	1944.54175	10.8	0.56%	1930.433	1923.7395	-6.7	-0.35%	1954.55	1930.43	-1.23%	1980.66	1923.74	-2.87%
		Utility Based High	2.291487	1954.55075	1980.65975	26.1	1.34%	1932.87525	1926.81125	-7.1	-0.37%	1919.93026	1920.57675	0.6	0.03%	1954.55	1919.93	-1.77%	1980.66	1920.58	-2.97%
	P(i)	Clear Sky w/Hg	2.728571	3740.7072	3664.0658	-56.6	-1.51%	3590.7948	3566.3462	-9.8	-0.27%	3443.7222	3472.2986	28.6	0.83%	3740.71	3443.72	-7.95%	3664.07	3472.30	-5.23%
	4	Clear Sky w/Hg	2.728571	3432.462	3475.2578	42.8	1.25%	3314.2584	3342.829	28.6	0.86%	3210.7452	3190.1912	-14.6	-0.45%	3432.46	3210.75	-6.46%	3475.26	3190.19	-8.21%
		NAAQS	2.728571	3481.214	3445.6014	-35.6	-1.02%	3336.6776	3332.0314	-4.6	-0.14%	3186.1858	3228.26	42.1	1.32%	3481.21	3186.19	-8.47%	3445.60	3228.26	-6.31%
		Utility Based (Coal)	2.728571	3663.9778	3544.0632	-139.9	-3.82%	3498.6726	3532.4584	33.8	0.97%	3314.759	3281.7012	-33.1	-1.00%	3663.98	3314.76	-9.53%	3544.06	3281.70	-7.42%
		Utility Based High	2.728571	3663.9778	3544.0632	-139.9	-3.82%	3344.804	3341.4048	-3.4	-0.10%	3210.277	3182.8354	-27.6	-0.86%	3663.98	3210.28	-12.36%	3544.06	3182.84	-10.20%
	FD(s)	Clear Sky w/Hg		2987.564	2987.956	0.4	0.01%	2994.4755	2985.91625	1.4	0.02%	2981.78575	2982.16925	0.4	0.01%	2987.56	2981.79	-0.19%	2987.97	2982.17	-0.20%
	5	Clear Sky w/Hg		2962.123	2960.07325	-2.0	-0.07%	2958.56425	2959.68725	1.3	0.04%	2955.01175	2954.1915	-0.8	-0.03%	2962.12	2955.01	-0.24%	2960.07	2954.19	-0.20%
		NAAQS		2962.3605	2963.091	0.8	0.02%	2961.13275	2960.55025	-0.6	-0.02%	2954.923	2957.20625	2.3	0.08%	2962.36	2954.92	-0.25%	2963.00	2957.21	-0.20%
		Utility Based (Coal)		2959.71075	2963.51175	3.8	0.13%	2961.7	2961.10475	-0.6	-0.02%	2956.43625	2956.81925	0.4	0.01%	2959.71	2956.44	-0.11%	2963.51	2959.82	-0.23%
		Utility Based High		2959.71075	2963.51175	3.8	0.13%	2958.64675	2960.45525	1.8	0.06%	2956.4755	2952.849	2.4	0.08%	2959.71	2956.48	-0.11%	2963.51	2952.85	-0.36%
	FD(j)	Clear Sky w/Hg	2.733197	3876.2	3895.00167	19.8	0.54%	3506.70297	3535.56935	25.9	0.74%	3348.78567	3375.91633	27.1	0.81%	3876.20	3348.79	-13.61%	3895.00	3375.92	-13.34%
	6	Clear Sky w/Hg	2.733197	3467.77433	3580.72433	113.0	3.26%	3316.909	3344.86867	27.8	0.84%	3146.14633	3099.51633	-47.6	-1.51%	3467.77	3146.15	-9.27%	3580.72	3098.52	-13.47%
		NAAQS	2.733197	3425.49733	3430.84367	5.3	0.16%	3218.982	3205.471	-13.5	-0.42%	3084.31633	3108.52467	22.2	0.72%	3425.50	3084.32	-9.96%	3430.84	3106.52	-9.43%
		Utility Based (Coal)	2.733197	3660.15367	3477.50133	-202.7	-5.54%	3460.22967	3520.86567	60.7	1.76%	3242.7	3173.381	-69.3	-2.14%	3660.15	3242.70	-11.39%	3477.50	3173.38	-8.75%
		Utility Based High	2.733197	3660.15367	3477.50133	-202.7	-5.54%	3293.11967	3295.157	2.0	0.06%	3194.90667	3194.42033	0.4	0.01%	3660.15	3194.91	-12.71%	3477.50	3194.43	-8.16%
	S(a)	Clear Sky w/Hg	2.868303	1292.25933	1289.26733	-3.0	-0.23%	1273.32567	1283.24133	-10.1	-0.80%	1243.24	1242.997	-0.2	-0.02%	1292.26	1243.24	-3.79%	1289.27	1243.00	-3.58%
	7	Clear Sky w/Hg	2.868303	1198.127	1209.42367	11.3	0.94%	1216.04133	1202.37567	-13.7	-1.12%	1189.46567	1201.63867	12.2	1.02%	1198.13	1189.47	-0.72%	1209.42	1201.64	-0.64%
		NAAQS	2.868303	1263.62867	1244.219	-19.4	-1.54%	1205.63833	1209.71633	4.1	0.34%	1210.53367	1192.72267	-17.8	-1.47%	1263.63	1210.53	-4.20%	1244.22	1192.72	-4.14%
		Utility Based (Coal)	2.868303	1259.17833	1274.95233	15.8	1.25%	1219.80267	1244.15467	24.5	2.01%	1212.42467	1182.18747	-30.2	-2.49%	1259.18	1212.42	-3.72%	1274.95	1182.19	-7.25%
		Utility Based High	2.868303	1259.17833	1274.95233	15.8	1.25%	1208.818	1221.13833	12.3	1.02%	1187.47833	1190.478	3.0	0.25%	1259.18	1187.48	-5.69%	1274.95	1190.48	-6.61%
	S(j)	Clear Sky w/Hg	2.705963	3757.67583	3642.35517	-115.1	-3.06%	3399.6125	3982.30017	-7.3	-0.32%	3588.76917	3631.7595	43.0	1.20%	3757.68	3588.77	-4.49%	3642.54	3631.76	-0.30%
	8	Clear Sky w/Hg	2.705963	3520.1465	3499.18483	-21.0	-0.60%	3407.52283	3396.085	-11.4	-0.34%	3209.44233	3235.9365	27.5	0.86%	3520.15	3209.44	-8.83%	3499.18	3235.94	-7.55%
		NAAQS	2.705963	3508.031	3503.05783	-5.0	-0.14%	3399.97283	3373.84117	-26.1	-0.77%	3196.6875	3207.096	10.4	0.33%	3508.03	3196.69	-8.88%	3503.06	3207.10	-8.46%
		Utility Based (Coal)	2.705963	3609.3725	3647.8155	38.4	1.07%	3646.69133	3578.503	31.8	0.89%	3389.55283	3342.04083	-27.5	-0.82%	3609.37	3389.55	-6.54%	3647.82	3342.04	-8.36%
		Utility Based High	2.705963	3609.3725	3647.8155	38.4	1.07%	3442.05467	3451.637	9.6	0.28%	3308.278	3239.671	-68.6	-2.07%	3609.37	3308.28	-8.34%	3647.82	3239.67	-11.19%
	C(y)	Clear Sky w/Hg		318.3972	318.6243	0.2	0.07%	318.382033	318.3957	0.0	0.00%	318.532133	318.388733	-0.2	-0.05%	318.40	318.53	0.04%	318.62	318.37	-0.08%
	9	Clear Sky w/Hg		318.2628	318.4486	0.2	0.06%	318.2963	318.411933	0.1	0.04%	318.210133	318.3391	0.1	0.04%	318.26	318.21	-0.02%	318.45	318.34	-0.03%
		NAAQS		318.5031	318.462933	0.0	-0.01%	318.456133	318.481333	0.0	0.01%	318.260233	318.299467	0.0	0.01%	318.50	318.27	-0.07%	318.46	318.30	-0.05%
		Utility Based (Coal)		318.275733	318.363267	0.1	0.02%	318.123567	318.431367	0.3	0.10%	318.419067	318.4187	0.0	0.00%	318.28	318.42	0.04%	318.36	318.42	0.02%
		Utility Based High		318.275733	318.363267	0.1	0.02%	318.432267	318.525367	0.1	0.03%	318.459867	318.4118	0.0	-0.02%	318.28	318.46	0.06%	318.36	318.41	0.02%
	BC(s)	Clear Sky w/Hg		109.017083	110.037333	1.0	0.94%	112.239767	112.791867	0.6	0.49%	110.76592	110.64747	-0.1	-0.12%	109.02	110.79	1.62%	110.04	110.65	0.55%
	10	Clear Sky w/Hg		109.9796	109.764683	-0.2	-0.19%	111.298825	109.993793	-1.3	-1.17%	110.908463	109.511947	-1.4	-1.26%	109.98	110.91	0.79%	109.76	109.51	-0.25%
		NAAQS		108.69907	109.25398	0.6	0.51%	109.44109	109.899907	0.4	0.36%	110.919983	109.379573	-1.5	-1.35%	108.70	110.92	2.04%	109.25	109.38	0.11%
		Utility Based (Coal)		110.42978	110.24152	-0.2	-0.17%	108.811203	110.13534	1.3	1.22%	109.989473	109.98512	0.0	0.00%	110.43	109.99	-0.40%	110.24	109.99	-0.23%
		Utility Based High		110.42978	110.24152	-0.2	-0.17%	109.305517	109.823423	0.5	0.29%	108.491393	109.43257	1.0	0.90%	110.43	108.49	-1.76%	110.24	109.43	-0.73%
	BC(i)	Clear Sky w/Hg		304.437267	304.5289	0.1	0.03%	305.0082	305.25595	0.2	0.08%	304.9754	304.4632	0.0	0.00%	304.44	304.98	0.18%	304.53	304.46	0.05%
	11	Clear Sky w/Hg		304.597267	304.515967	-0.1	-0.03%	304.745333	304.388267	-0.4	-0.12%	304.5642	304.338233	-0.2	-0.08%	304.60	304.56	-0.09%	304.52	304.34	-0.06%
		NAAQS		304.327233	304.349133	0.0	0.01%	304.403333	304.459067	0.1	0.02%	304.617167	304.3468	-0.3	-0.09%	304.33	304.62	0.10%	304.35	304.35	0.00%
		Utility Based (Coal)		304.652533	304.8427	0.0	0.00%	304.3471	304.627633	0.3	0.09%	304.4053	304.520133	0.1	0.04%	304.65	304.41	-0.08%	304.64	304.52	-0.04%
		Utility Based High		304.652533	304.8427	0.0	0.00%	304.381067	304.475367	0.1	0.03%	304.129033	304.466967	0.3	0.09%	304.65	304.13	-0.17%	304.84	304.47	-0.08%
	BC(j)	Clear Sky w/Hg		1978.37634	1979.34766	1.0	0.05%	1976.56572	1975.40668	-1.2	-0.06%	1977.019164	1977.22174	0.2	0.01%	1978.38	1978.19	-0.01%	1979.35	1977.22	-0.11%
	12	Clear Sky w/Hg		1977.94858	1977.25974	-0.7	-0.03%	1975.68958	1976.28674	0.6	0.03%	1974.96836	1975.68974	0.7	0.04%	1977.95	1974.97	-0.16%	1977.26	1975.67	-0.08%
		NAAQS		1977.88822	1979.02128	1.1	0.06%	1977.5385	1977.42802	-0.1	-0.01%	1975.8663	1976.003	0.1	0.01%	1977.89	1975.89	-0.10%	1979.02	1976.00	-0.15%
		Utility Based (Coal)		1977.74858	1977.17882	-0.6	-0.03%	1976.98008	1976.78136	-0.2	-0.01%	1975.89786	1978.55398	0.9	0.04%	1977.75	1975.90	-0.10%	1977.18	1978.55	-0.03%
		Utility Based High		1977.74858	1977.17882	-0.6	-0.03%	1978.10018	1977.34702	-0.8	-0.04%	1974.9945	1974.9872	0.0	0.00%	1977.75	1974.99	-0.14%	1977.18	1974.99	-0.11%
	BC(s)	Clear Sky w/Hg		1829.61307	1829.64445	0.2	0.01%	1829.00255	1829.25337	0.3	0.01%	1828.28252	1828.47565	0.2	0.01%	1829.61	1828.28	-0.07%	1829.64	1828.48	-0.07%
	13	Clear Sky w/Hg		1828.23802	1828.35923	0.1	0.01%	1827.5811	1827.41187	-0.2	-0.01%	1826.74565	1828.45892	-0.3	-0.02%	1828.24	1828.75	0.03%	1828.36	1828.46	-0.10%
		NAAQS		1828.3729	1828.17465	-0.2	-0.01%	1827.59188	1827.42725	-0.2	-0.01%	1826.10945	1826.35238	0.2	0.01%	1828.37	1826.11	-0.12%	1828.17	1826.35	-0.10%
		Utility Based (Coal)		1828.00037	1828.338	0.3	0.02%	1827.84922	1828.07638	0.2	0.01%	1828.85365	1829.48707	-0.4	-0.02%	1828.00	1828.85	-0.06%	1828.34	1826.48	-0.10%
		Utility Based High		1828.00037	1828.338	0.3	0.02%	1827.27767	1827.9231	0.6	0.03%	1828.85365	1828.37252	-0.5	-0.03%	1828.00	1828.85	-0.06%	1828.34	1826.37	-0.11%
	SB(s)	Clear Sky w/Hg	6.077946	34.2223332	35.01089	1.8	5.22%	52.0324533	33.35716	1.3	4.14%	34.8469467	35.4975633	0.7	1.55%	34.22	34.84	1.81%	36.01	35.50	-1.43%
	14	Clear Sky w/Hg	6.077946	31.8454233	32.3885287	0.5	1.71%	26.7787433	26.2841567	0.5	2.01%	25.2027533	24.905705	-0.3	-1.18%	31.84	25.20	-20.87%	32.39	24.91	-23.10%
		NAAQS	6.077946	29.8040467	29.72607	0.1	0.42%	26.1766103	26.034742	-0.1	-0.54%	24.189564	25.0473643	0.9	3.58%	29.80	24.19	-18.83%	29.73	25.05	-15.75%
		Utility Based (Coal)	6.077946	39.8532033	39.54513	-1.3	-3.26%	32.5347533	33.4475767	0.9	2.71%	28.37267	27.1688767	-1.2	-4.23%	39.85	28.37	-28.81%	39.55	27.17	-29.31%
		Utility Based High	6.077946	39.8532033	38.54513	-1.3	-3.26%	31.6494167	31.07214	-0.5	-1.51%	24.4188683	25.944797	1.5	6.35%	39.85	24.42	-38.72%	38.55	25.94	-32.69%
	SB(j)	Clear Sky w/Hg		578.183917	578.175117	0.0	0.00%	578.183917	578.155967	0.0	0.00%	578.093383	578.09345	0.0	0.00%	578.18	578.09	-0.01%	578.18	578.09	-0.01%
	15	Clear Sky w/Hg		578.049867	577.923433	-0.1	-0.02%	577.996717	577.8625	-0.1	-0.02%	577.71015	577.8573	0.0	-0.01%	578.05	577.71	-0.06%	577.92	577.67	-0.04%
		NAAQS		577.880283	578.039767	0.2	0.03%	578.00675	578.094667	0.1	0.02%	577.782733	577.79485	0.0	0.00%	577.88	577.78	-0.02%	578.04	577.79	-0.04%
		Utility Based (Coal)		578.02335	578.064933	0.0	0.01%	577.843417	577.938117	0.1	0.02%	577.9016	578.093933	0.1	0.01%	578.02	577.90	-0.01%	578.06	578.06	0.00%
		Utility Based High		578.02335	578.064933	0.0	0.01%	577.880667	577.938167	0.1	0.01%	577.7473	577.899217	0.2	0.03%	578.02	577.75	-0.05%	578.06	577.90	-0.03%

TABLE 14
Belleville Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Belleville	ES(s)	Clear Sky w/Hg	4.46	1407.7	1406.3	-1.4	-0.10%	1404.0	1409.1	5.1	0.36%	1375.2	1376.7	1.5	0.11%	1407.73	1375.23	-2.31%	1406.30	1376.74	-2.10%
	1	Clear Sky wo/Hg	4.46	1379.2	1396.0	16.8	1.22%	1354.8	1364.2	9.4	0.69%	1341.3	1345.5	4.2	0.31%	1379.18	1341.31	-2.75%	1396.01	1345.46	-3.62%
		NAAQS	4.46	1389.6	1386.3	-3.3	-0.24%	1367.0	1365.6	-1.4	-0.10%	1342.4	1355.4	13.0	0.97%	1389.61	1342.40	-3.40%	1386.32	1355.41	-2.23%
		Utility Based (Coal)	4.46	1419.6	1382.4	-37.2	-2.62%	1375.4	1382.2	6.8	0.49%	1362.0	1356.3	-5.7	-0.42%	1419.58	1361.98	-4.06%	1382.35	1356.32	-1.88%
		Utility Based High	4.46	1419.6	1382.4	-37.2	-2.62%	1362.0	1364.7	2.7	0.20%	1351.8	1348.5	-3.4	-0.25%	1419.58	1351.85	-4.77%	1382.35	1348.49	-2.45%
	ES(f)	Clear Sky w/Hg	5.39	1030.9	1036.0	5.2	0.50%	1012.8	1019.4	6.5	0.65%	999.0	997.0	-2.0	-0.20%	1030.87	998.99	-3.09%	1036.05	997.00	-3.77%
	2	Clear Sky wo/Hg	5.39	998.1	1019.4	21.2	2.13%	983.6	988.2	4.6	0.47%	953.1	954.0	0.9	0.10%	998.13	953.06	-4.63%	1019.35	953.97	-6.41%
		NAAQS	5.39	1010.8	1003.5	-7.3	-0.72%	977.2	977.9	0.7	0.07%	953.4	953.0	-0.4	-0.04%	1010.78	953.43	-5.67%	1003.46	953.01	-5.03%
		Utility Based (Coal)	5.39	1038.2	1000.2	-37.9	-3.66%	998.1	1009.0	10.8	1.09%	975.1	971.0	-4.1	-0.42%	1038.19	975.07	-6.06%	1000.24	970.96	-2.93%
		Utility Based High	5.39	1038.2	1000.2	-37.9	-3.66%	977.2	977.2	0.1	0.01%	964.2	965.1	0.9	0.10%	1038.19	964.20	-7.13%	1000.24	965.13	-3.51%
	P(s)	Clear Sky w/Hg	2.95	2651.2	2600.7	-50.6	-1.91%	2599.4	2592.5	-7.0	-0.27%	2594.7	2592.4	-2.4	-0.09%	2651.24	2594.73	-2.13%	2600.68	2592.36	-0.32%
	3	Clear Sky wo/Hg	2.95	2555.2	2566.6	11.4	0.45%	2561.8	2554.5	-7.3	-0.29%	2529.8	2554.7	24.9	0.99%	2555.24	2529.77	-1.00%	2566.62	2554.69	-0.46%
		NAAQS	2.95	2574.5	2587.6	13.1	0.51%	2580.1	2566.1	-14.0	-0.54%	2546.4	2557.5	11.1	0.43%	2574.47	2546.43	-1.09%	2587.56	2557.48	-1.16%
		Utility Based (Coal)	2.95	2584.8	2596.7	11.9	0.46%	2547.8	2558.1	10.2	0.40%	2541.2	2542.6	1.4	0.05%	2584.79	2541.22	-1.69%	2596.71	2542.60	-2.08%
		Utility Based High	2.95	2584.8	2596.7	11.9	0.46%	2547.1	2550.3	3.2	0.13%	2536.2	2527.5	-8.7	-0.34%	2584.79	2536.22	-1.88%	2596.71	2527.50	-2.67%
	P(l)	Clear Sky w/Hg	3.42	4945.8	4876.7	-69.2	-1.40%	4691.4	4701.6	10.2	0.22%	4622.4	4651.8	29.4	0.64%	4945.85	4622.38	-6.54%	4876.66	4651.81	-4.61%
	4	Clear Sky wo/Hg	3.42	4557.1	4601.3	44.2	0.97%	4465.1	4501.0	36.0	0.81%	4303.1	4282.0	-21.2	-0.49%	4557.15	4303.14	-5.57%	4601.34	4281.98	-6.94%
		NAAQS	3.42	4631.9	4567.3	-64.6	-1.39%	4458.2	4449.1	-9.0	-0.20%	4277.1	4337.4	60.3	1.41%	4631.88	4277.07	-7.66%	4567.29	4337.37	-5.03%
		Utility Based (Coal)	3.42	4896.8	4665.0	-231.8	-4.73%	4578.0	4662.9	84.9	1.86%	4461.3	4417.1	-44.2	-0.99%	4896.80	4461.31	-8.88%	4664.96	4417.09	-5.31%
		Utility Based High	3.42	4896.8	4665.0	-231.8	-4.73%	4492.4	4481.2	-11.3	-0.25%	4322.3	4332.0	9.7	0.22%	4896.80	4322.29	-11.73%	4664.96	4331.98	-7.14%
	FD(l)	Clear Sky w/Hg	3.42	4807.4	4815.4	8.1	0.17%	4630.8	4689.0	58.2	1.26%	4489.3	4484.0	-5.3	-0.12%	4807.36	4489.29	-6.62%	4815.43	4483.96	-6.88%
	6	Clear Sky wo/Hg	3.42	4522.1	4680.5	158.5	3.50%	4403.8	4470.7	66.9	1.52%	4185.2	4153.9	-31.2	-0.75%	4522.09	4185.17	-7.46%	4680.54	4153.93	-11.25%
		NAAQS	3.42	4581.8	4536.1	-45.7	-1.00%	4343.4	4345.6	2.2	0.05%	4156.3	4202.2	45.9	1.11%	4581.78	4156.30	-9.29%	4536.10	4202.23	-7.36%
		Utility Based (Coal)	3.42	4900.1	4579.3	-320.7	-6.55%	4493.0	4611.7	118.7	2.64%	4335.4	4269.2	-66.2	-1.53%	4900.08	4335.45	-11.52%	4579.35	4269.20	-6.77%
		Utility Based High	3.42	4900.1	4579.3	-320.7	-6.55%	4376.9	4380.1	3.1	0.07%	4202.0	4208.1	6.1	0.15%	4900.08	4201.96	-14.25%	4579.35	4208.11	-8.11%
	S(s)	Clear Sky w/Hg	3.67	1941.9	1924.8	-17.2	-0.88%	1924.8	1913.0	-11.8	-0.61%	1902.5	1895.7	-6.9	-0.36%	1941.94	1902.54	-2.03%	1924.78	1895.69	-1.51%
	7	Clear Sky wo/Hg	3.67	1852.6	1865.2	12.6	0.68%	1872.9	1871.6	-1.3	-0.07%	1852.0	1860.2	8.2	0.44%	1852.61	1851.99	-0.03%	1865.22	1860.18	-0.27%
		NAAQS	3.67	1911.0	1886.3	-24.7	-1.29%	1868.0	1863.6	-4.4	-0.23%	1853.3	1840.9	-12.4	-0.67%	1911.01	1853.30	-3.02%	1886.32	1840.86	-2.41%
		Utility Based (Coal)	3.67	1929.8	1935.4	5.6	0.29%	1870.6	1914.4	43.8	2.34%	1856.0	1834.6	-21.4	-1.15%	1929.82	1856.05	-3.82%	1935.38	1834.64	-5.21%
		Utility Based High	3.67	1929.8	1935.4	5.6	0.29%	1854.3	1876.1	21.8	1.18%	1854.0	1845.2	-8.8	-0.47%	1929.82	1853.98	-3.93%	1935.38	1845.21	-4.66%
	S(l)	Clear Sky w/Hg	3.39	4985.0	4844.0	-141.0	-2.83%	4867.0	4860.1	-6.9	-0.14%	4774.1	4786.6	12.5	0.26%	4984.99	4774.14	-4.23%	4844.02	4786.61	-1.19%
	8	Clear Sky wo/Hg	3.39	4675.6	4655.4	-20.2	-0.43%	4577.0	4541.2	-35.9	-0.78%	4332.7	4350.7	17.9	0.41%	4675.62	4332.73	-7.33%	4655.38	4350.67	-6.55%
		NAAQS	3.39	4679.8	4705.9	26.1	0.56%	4588.7	4551.7	-37.0	-0.81%	4341.6	4329.0	-12.7	-0.29%	4679.77	4341.62	-7.23%	4705.85	4328.95	-8.01%
		Utility Based (Coal)	3.39	4841.8	4829.0	-12.8	-0.26%	4705.7	4774.0	68.2	1.45%	4512.3	4480.0	-32.3	-0.72%	4841.77	4512.27	-6.81%	4828.97	4480.00	-7.23%
		Utility Based High	3.39	4841.8	4829.0	-12.8	-0.26%	4642.4	4661.0	18.6	0.40%	4485.5	4429.4	-56.1	-1.25%	4841.77	4485.53	-7.36%	4828.97	4429.44	-8.27%
	SB(s)	Clear Sky w/Hg	5.09	40.4	41.6	1.2	3.00%	37.5	37.7	0.1	0.34%	42.1	42.5	0.4	0.97%	40.37	42.12	4.32%	41.58	42.52	2.26%
	14	Clear Sky wo/Hg	5.09	39.2	38.8	-0.4	-1.08%	32.4	32.0	-0.4	-1.28%	31.5	30.9	-0.6	-1.96%	39.23	31.51	-19.69%	38.80	30.89	-20.40%
		NAAQS	5.09	36.5	37.0	0.5	1.32%	34.2	34.4	0.2	0.56%	31.4	32.1	0.7	2.33%	36.48	31.35	-14.07%	36.96	32.08	-13.21%
		Utility Based (Coal)	5.09	45.8	45.6	-0.3	-0.57%	37.9	38.7	0.7	1.97%	33.6	33.4	-0.2	-0.56%	45.83	33.61	-26.66%	45.57	33.42	-26.66%
		Utility Based High	5.09	45.8	45.6	-0.3	-0.57%	38.4	37.1	-1.4	-3.61%	32.3	34.5	2.2	6.95%	45.83	32.25	-29.64%	45.57	34.49	-24.31%

TABLE 15
Racine Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Racine	ES(s)	Clear Sky w/Hg	2.84	977.5	980.9	3.4	0.35%	968.1	973.1	5.0	0.52%	956.0	956.3	0.3	0.03%	977.54	955.98	-2.21%	980.94	956.27	-2.51%
	1	Clear Sky wo/Hg	2.84	958.2	968.7	10.5	1.10%	950.9	958.7	7.8	0.82%	930.8	930.1	-0.7	-0.07%	958.17	930.76	-2.86%	968.68	930.08	-3.96%
		NAAQS	2.84	963.0	959.5	-3.6	-0.37%	944.1	949.5	5.4	0.58%	934.4	939.0	4.6	0.49%	963.03	934.39	-2.97%	959.45	939.00	-2.13%
		Utility Based (Coal)	2.84	984.8	959.3	-25.5	-2.59%	954.0	961.8	7.8	0.82%	938.3	937.4	-0.9	-0.10%	984.85	938.33	-4.72%	959.32	937.43	-2.28%
		Utility Based High	2.84	984.8	959.3	-25.5	-2.59%	947.8	948.1	0.4	0.04%	933.1	937.5	4.5	0.48%	984.85	933.07	-5.26%	959.32	937.54	-2.27%
	ES(f)	Clear Sky w/Hg	3.12	607.6	612.5	4.9	0.81%	595.9	599.2	3.3	0.55%	593.5	589.7	-3.7	-0.63%	607.57	593.45	-2.32%	612.47	589.72	-3.71%
	2	Clear Sky wo/Hg	3.12	589.9	600.5	10.5	1.78%	582.4	585.3	2.9	0.49%	561.5	560.7	-0.8	-0.14%	589.94	561.51	-4.82%	600.46	560.74	-6.61%
		NAAQS	3.12	594.9	591.8	-3.1	-0.52%	572.7	575.8	3.0	0.52%	561.1	561.1	0.0	0.00%	594.91	561.10	-5.68%	591.82	561.07	-5.20%
		Utility Based (Coal)	3.12	610.3	593.2	-17.1	-2.80%	589.1	596.7	7.7	1.30%	574.3	573.1	-1.3	-0.22%	610.33	574.34	-5.90%	593.23	573.07	-3.35%
		Utility Based High	3.12	610.3	593.2	-17.1	-2.80%	578.1	577.9	-0.2	-0.03%	567.1	569.9	2.8	0.49%	610.33	567.08	-7.09%	593.23	569.86	-3.94%
	P(s)	Clear Sky w/Hg	2.80	2662.5	2625.4	-37.1	-1.39%	2626.7	2622.3	-4.4	-0.17%	2628.0	2630.3	2.4	0.09%	2662.52	2627.96	-1.30%	2625.39	2630.31	0.19%
	3	Clear Sky wo/Hg	2.80	2602.8	2599.2	-3.5	-0.14%	2612.9	2596.8	-16.1	-0.62%	2578.6	2593.8	15.2	0.59%	2602.75	2578.61	-0.93%	2599.22	2593.81	-0.21%
		NAAQS	2.80	2616.2	2630.6	14.4	0.55%	2611.1	2610.4	-0.7	-0.03%	2593.1	2596.2	3.1	0.12%	2616.23	2593.08	-0.88%	2630.62	2596.23	-1.31%
		Utility Based (Coal)	2.80	2607.3	2613.6	6.3	0.24%	2584.1	2596.4	12.2	0.47%	2582.8	2577.5	-5.3	-0.20%	2607.34	2582.79	-0.94%	2613.60	2577.54	-1.38%
		Utility Based High	2.80	2607.3	2613.6	6.3	0.24%	2583.5	2590.2	6.7	0.26%	2584.1	2576.5	-7.6	-0.29%	2607.34	2584.12	-0.89%	2613.60	2576.50	-1.42%
	P(i)	Clear Sky w/Hg	2.76	3924.4	3870.4	-54.0	-1.38%	3675.1	3681.8	6.6	0.18%	3658.8	3672.6	13.8	0.38%	3924.38	3658.75	-6.77%	3870.36	3672.57	-5.11%
	4	Clear Sky wo/Hg	2.76	3562.1	3644.9	82.9	2.33%	3491.6	3509.3	17.7	0.51%	3334.0	3304.0	-29.9	-0.90%	3562.07	3333.95	-6.40%	3644.93	3304.04	-9.35%
		NAAQS	2.76	3616.5	3578.7	-37.7	-1.04%	3444.4	3460.5	16.0	0.47%	3306.2	3378.0	71.8	2.17%	3616.47	3306.18	-8.58%	3578.74	3378.01	-5.61%
		Utility Based (Coal)	2.76	3879.2	3668.9	-210.3	-5.42%	3574.2	3627.5	53.3	1.49%	3470.2	3412.2	-58.0	-1.67%	3879.22	3470.25	-10.54%	3668.94	3412.21	-7.00%
		Utility Based High	2.76	3879.2	3668.9	-210.3	-5.42%	3488.4	3495.9	7.5	0.21%	3330.8	3312.8	-18.0	-0.54%	3879.22	3330.79	-14.14%	3668.94	3312.81	-9.71%
	FD(i)	Clear Sky w/Hg	2.76	3815.4	3835.1	19.8	0.52%	3623.1	3661.9	38.7	1.07%	3546.8	3539.7	-7.2	-0.20%	3815.36	3546.83	-7.04%	3835.13	3539.67	-7.70%
	6	Clear Sky wo/Hg	2.76	3549.2	3699.7	150.5	4.24%	3470.5	3543.3	72.8	2.10%	3243.1	3181.4	-61.7	-1.90%	3549.24	3243.12	-8.62%	3699.70	3181.42	-14.01%
		NAAQS	2.76	3593.6	3567.1	-26.5	-0.74%	3326.0	3353.6	27.6	0.83%	3186.0	3229.5	43.6	1.37%	3593.62	3185.95	-11.34%	3567.12	3229.51	-9.46%
		Utility Based (Coal)	2.76	3867.9	3641.9	-226.0	-5.84%	3497.5	3631.5	134.1	3.83%	3349.4	3298.3	-51.1	-1.53%	3867.94	3349.42	-13.41%	3641.92	3298.31	-9.43%
		Utility Based High	2.76	3867.9	3641.9	-226.0	-5.84%	3427.1	3453.8	26.7	0.78%	3229.0	3256.2	27.2	0.84%	3867.94	3228.98	-16.52%	3641.92	3256.15	-10.59%
	S(s)	Clear Sky w/Hg	3.37	1654.0	1642.8	-11.3	-0.68%	1631.9	1629.8	-2.2	-0.13%	1625.9	1615.2	-10.6	-0.65%	1654.05	1625.86	-1.70%	1642.78	1615.24	-1.68%
	7	Clear Sky wo/Hg	3.37	1572.7	1585.1	12.4	0.79%	1598.1	1578.0	-20.2	-1.26%	1574.5	1570.0	-4.5	-0.29%	1572.68	1574.52	0.12%	1585.13	1570.00	-0.95%
		NAAQS	3.37	1632.8	1620.5	-12.3	-0.75%	1578.1	1583.9	5.8	0.37%	1569.4	1566.4	-3.0	-0.19%	1632.81	1569.42	-3.88%	1620.55	1566.43	-3.34%
		Utility Based (Coal)	3.37	1643.1	1647.6	4.5	0.27%	1595.0	1605.1	10.1	0.63%	1573.9	1543.9	-30.0	-1.90%	1643.13	1573.85	-4.22%	1647.62	1543.90	-6.30%
		Utility Based High	3.37	1643.1	1647.6	4.5	0.27%	1564.0	1585.7	21.7	1.38%	1568.7	1588.6	19.9	1.27%	1643.13	1568.68	-4.53%	1647.62	1588.61	-3.58%
	S(i)	Clear Sky w/Hg	2.74	3943.2	3822.6	-120.6	-3.06%	3848.4	3850.4	2.1	0.05%	3769.7	3777.7	8.0	0.21%	3943.21	3769.69	-4.40%	3822.64	3777.69	-1.18%
	8	Clear Sky wo/Hg	2.74	3677.2	3673.9	-3.3	-0.09%	3580.8	3541.3	-39.5	-1.10%	3382.1	3393.4	11.3	0.33%	3677.21	3382.10	-8.03%	3673.91	3393.42	-7.63%
		NAAQS	2.74	3671.4	3734.8	63.4	1.73%	3575.3	3564.3	-11.1	-0.31%	3362.8	3368.7	5.9	0.18%	3671.41	3362.76	-8.41%	3734.77	3368.65	-9.80%
		Utility Based (Coal)	2.74	3839.5	3823.1	-16.4	-0.43%	3723.5	3743.8	20.4	0.55%	3525.0	3534.0	9.1	0.26%	3839.53	3524.98	-8.19%	3823.09	3534.03	-7.56%
		Utility Based High	2.74	3839.5	3823.1	-16.4	-0.43%	3652.4	3656.2	3.8	0.11%	3527.4	3476.7	-50.7	-1.44%	3839.53	3527.36	-8.13%	3823.09	3476.69	-9.06%
	SB(s)	Clear Sky w/Hg	2.33	20.4	21.0	0.6	3.13%	18.9	19.1	0.2	1.10%	19.3	19.7	0.4	1.98%	20.40	19.34	-5.20%	21.04	19.72	-6.25%
	14	Clear Sky wo/Hg	2.33	19.9	19.0	-1.0	-4.84%	16.4	16.3	-0.2	-0.98%	15.6	15.3	-0.3	-1.69%	19.93	15.60	-21.75%	18.97	15.33	-19.16%
		NAAQS	2.33	17.7	17.8	0.2	0.96%	16.4	16.5	0.1	0.33%	17.3	16.0	-1.3	-7.72%	17.67	17.29	-2.12%	17.84	15.96	-10.54%
		Utility Based (Coal)	2.33	21.2	20.5	-0.7	-3.23%	18.9	19.0	0.1	0.32%	17.6	18.1	0.5	2.99%	21.23	17.56	-17.33%	20.54	18.08	-11.98%
		Utility Based High	2.33	21.2	20.5	-0.7	-3.23%	18.1	17.9	-0.1	-0.77%	17.1	16.7	-0.4	-2.28%	21.23	17.10	-19.46%	20.54	16.71	-18.67%

TABLE 16
R C Byrd Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
RC Byrd	ES(s)	Clear Sky w/Hg	2.18	810.4	815.8	5.5	0.67%	817.9	819.5	1.6	0.19%	810.3	807.7	-2.6	-0.32%	810.36	810.28	-0.01%	815.83	807.65	-1.00%
	1	Clear Sky wo/Hg	2.18	814.0	817.7	3.7	0.46%	803.6	806.3	2.7	0.33%	798.2	798.8	0.6	0.08%	814.01	798.19	-1.94%	817.71	798.80	-2.31%
		NAAQS	2.18	810.2	812.6	2.4	0.29%	803.2	805.8	2.6	0.32%	796.3	796.7	0.4	0.05%	810.17	796.27	-1.72%	812.56	796.68	-1.95%
		Utility Based (Coal)	2.18	819.2	806.1	-13.1	-1.60%	803.4	808.1	4.7	0.59%	801.0	797.8	-3.2	-0.41%	819.18	801.02	-2.22%	806.10	797.77	-1.03%
		Utility Based High	2.18	819.2	806.1	-13.1	-1.60%	801.7	800.1	-1.6	-0.20%	793.1	794.9	1.8	0.22%	819.18	793.09	-3.18%	806.10	794.87	-1.39%
	ES(f)	Clear Sky w/Hg	3.38	679.7	683.9	4.2	0.62%	682.5	685.5	3.0	0.44%	676.5	673.7	-2.8	-0.41%	679.71	676.52	-0.47%	683.95	673.74	-1.49%
	2	Clear Sky wo/Hg	3.38	681.1	689.2	8.1	1.19%	665.1	669.3	4.2	0.63%	653.0	655.2	2.1	0.33%	681.05	653.04	-4.11%	689.19	655.18	-4.93%
		NAAQS	3.38	676.4	678.7	2.3	0.34%	665.7	667.0	1.2	0.19%	652.0	652.7	0.6	0.10%	676.37	652.03	-3.60%	678.67	652.67	-3.93%
		Utility Based (Coal)	3.38	682.6	668.1	-14.5	-2.13%	655.7	662.5	6.8	1.04%	648.4	646.6	-1.8	-0.27%	682.57	648.37	-5.01%	668.05	646.60	-3.21%
		Utility Based High	3.38	682.6	668.1	-14.5	-2.13%	654.9	650.9	-4.0	-0.61%	634.9	639.1	4.2	0.67%	682.57	634.87	-6.89%	668.05	639.12	-4.33%
	P(s)	Clear Sky w/Hg	1.90	1879.8	1870.3	-9.5	-0.51%	1874.0	1869.5	-4.4	-0.24%	1868.9	1876.1	7.3	0.39%	1879.78	1868.88	-0.58%	1870.27	1876.13	0.31%
	3	Clear Sky wo/Hg	1.90	1857.8	1856.9	-0.9	-0.05%	1861.4	1855.5	-5.9	-0.31%	1848.0	1859.3	11.3	0.61%	1857.79	1847.96	-0.53%	1856.93	1859.30	0.13%
		NAAQS	1.90	1860.3	1872.9	12.6	0.68%	1871.8	1867.4	-4.4	-0.23%	1857.2	1852.0	-5.2	-0.28%	1860.29	1857.21	-0.17%	1872.87	1851.99	-1.12%
		Utility Based (Coal)	1.90	1856.4	1863.0	6.6	0.35%	1843.7	1850.1	6.4	0.35%	1842.1	1838.7	-3.4	-0.18%	1856.42	1842.05	-0.77%	1862.98	1838.68	-1.30%
		Utility Based High	1.90	1856.4	1863.0	6.6	0.35%	1843.8	1841.5	-2.4	-0.13%	1844.6	1837.9	-6.7	-0.36%	1856.42	1844.59	-0.64%	1862.98	1837.89	-1.35%
	P(l)	Clear Sky w/Hg	3.22	4608.4	4573.6	-34.8	-0.76%	4497.9	4500.3	2.3	0.05%	4474.7	4505.5	30.8	0.69%	4608.44	4474.66	-2.90%	4573.60	4505.51	-1.49%
	4	Clear Sky wo/Hg	3.22	4405.8	4513.8	108.0	2.45%	4283.6	4307.5	24.0	0.56%	4116.6	4110.0	-6.6	-0.16%	4405.78	4116.63	-6.56%	4513.78	4110.02	-8.95%
		NAAQS	3.22	4381.0	4372.8	-8.1	-0.19%	4264.2	4287.9	23.7	0.56%	4131.4	4181.9	50.5	1.22%	4380.97	4131.37	-5.70%	4372.82	4181.88	-4.37%
		Utility Based (Coal)	3.22	4555.5	4352.8	-202.7	-4.45%	4201.0	4240.7	39.7	0.94%	4075.1	4026.8	-48.3	-1.19%	4555.46	4075.14	-10.54%	4352.78	4026.80	-7.49%
		Utility Based High	3.22	4555.5	4352.8	-202.7	-4.45%	4092.7	4130.3	37.6	0.92%	3901.5	3930.5	29.0	0.74%	4555.46	3901.47	-14.36%	4352.78	3930.47	-9.70%
	FD(l)	Clear Sky w/Hg	3.22	4479.5	4476.7	-2.8	-0.06%	4474.1	4513.1	38.9	0.87%	4374.5	4360.2	-14.3	-0.33%	4479.50	4374.49	-2.34%	4476.71	4360.19	-2.60%
	6	Clear Sky wo/Hg	3.22	4396.8	4549.8	152.9	3.48%	4228.7	4311.0	82.3	1.95%	4059.7	4007.0	-52.7	-1.30%	4396.84	4059.70	-7.67%	4549.75	4006.96	-11.93%
		NAAQS	3.22	4332.5	4332.9	0.4	0.01%	4173.9	4202.6	28.7	0.69%	3973.3	4019.8	46.5	1.17%	4332.46	3973.27	-8.29%	4332.86	4019.79	-7.23%
		Utility Based (Coal)	3.22	4542.1	4292.6	-249.5	-5.49%	4098.8	4216.8	118.0	2.88%	3988.5	3919.2	-69.3	-1.74%	4542.09	3988.49	-12.19%	4292.56	3919.16	-8.70%
		Utility Based High	3.22	4542.1	4292.6	-249.5	-5.49%	4078.4	4077.8	-0.7	-0.02%	3804.5	3847.2	42.7	1.12%	4542.09	3804.50	-16.24%	4292.56	3847.17	-10.38%
	S(s)	Clear Sky w/Hg	1.51	930.4	927.9	-2.6	-0.28%	927.9	924.1	-3.8	-0.41%	921.3	922.9	1.7	0.18%	930.44	921.28	-0.98%	927.86	922.94	-0.53%
	7	Clear Sky wo/Hg	1.51	910.6	918.3	7.7	0.85%	920.8	915.0	-5.8	-0.63%	912.9	914.2	1.2	0.14%	910.57	912.94	0.26%	918.27	914.19	-0.44%
		NAAQS	1.51	928.2	921.2	-7.0	-0.75%	917.4	916.1	-1.3	-0.15%	912.7	903.4	-9.4	-1.03%	928.19	912.73	-1.67%	921.19	903.35	-1.94%
		Utility Based (Coal)	1.51	925.1	922.6	-2.5	-0.27%	906.6	911.0	4.4	0.48%	898.4	891.1	-7.3	-0.82%	925.12	898.43	-2.88%	922.62	891.10	-3.42%
		Utility Based High	1.51	925.1	922.6	-2.5	-0.27%	897.9	904.0	6.0	0.67%	897.2	897.4	0.2	0.02%	925.12	897.23	-3.01%	922.62	897.43	-2.73%
	S(l)	Clear Sky w/Hg	3.19	4654.3	4544.9	-109.4	-2.35%	4690.2	4694.0	3.8	0.08%	4593.7	4621.2	27.5	0.60%	4654.29	4593.73	-1.30%	4544.93	4621.19	1.68%
	8	Clear Sky wo/Hg	3.19	4504.1	4505.2	1.1	0.02%	4417.2	4400.6	-16.6	-0.38%	4233.3	4246.5	13.2	0.31%	4504.13	4233.33	-6.01%	4505.23	4246.53	-5.74%
		NAAQS	3.19	4473.2	4492.8	19.7	0.44%	4436.4	4394.8	-41.7	-0.94%	4204.6	4198.0	-6.5	-0.16%	4473.16	4204.56	-6.00%	4492.85	4198.03	-6.56%
		Utility Based (Coal)	3.19	4543.0	4523.6	-19.4	-0.43%	4406.5	4399.9	-6.5	-0.15%	4220.9	4178.7	-42.2	-1.00%	4543.03	4220.95	-7.09%	4523.59	4178.70	-7.62%
		Utility Based High	3.19	4543.0	4523.6	-19.4	-0.43%	4297.5	4325.6	28.1	0.65%	4145.7	4105.7	-40.0	-0.97%	4543.03	4145.68	-8.75%	4523.59	4105.67	-9.24%
	SB(s)	Clear Sky w/Hg	2.40	23.0	22.0	-1.0	-4.27%	21.8	22.1	0.2	1.09%	22.8	23.2	0.4	1.57%	22.99	22.82	-0.74%	22.01	23.18	5.32%
	14	Clear Sky wo/Hg	2.40	22.8	22.5	-0.2	-1.01%	19.4	18.8	-0.6	-2.92%	18.4	18.1	-0.3	-1.54%	22.75	18.36	-19.31%	22.52	18.08	-19.74%
		NAAQS	2.40	21.8	21.5	-0.3	-1.35%	20.1	20.1	-0.1	-0.26%	18.7	18.8	0.1	0.49%	21.83	18.72	-14.26%	21.54	18.81	-12.56%
		Utility Based (Coal)	2.40	22.5	20.8	-1.7	-7.69%	20.6	20.9	0.3	1.33%	18.5	19.0	0.5	2.65%	22.48	18.51	-17.67%	20.75	19.00	-8.45%
		Utility Based High	2.40	22.5	20.8	-1.7	-7.69%	20.1	20.1	0.0	0.14%	17.2	17.9	0.6	3.63%	22.48	17.24	-23.33%	20.75	17.86	-13.94%

TABLE 17
Greenup Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Greenup	ES(s)	Clear Sky w/Hg	4.11	1570.9	1582.0	11.1	0.71%	1582.3	1585.8	3.5	0.22%	1564.8	1563.1	-1.8	-0.11%	1570.91	1564.83	-0.39%	1582.02	1563.07	-1.20%
	1	Clear Sky wo/Hg	4.11	1588.7	1598.0	9.3	0.59%	1554.7	1561.7	7.0	0.45%	1540.2	1540.5	0.3	0.02%	1588.70	1540.20	-3.05%	1598.03	1540.49	-3.60%
		NAAQS	4.11	1572.6	1582.5	10.0	0.64%	1556.2	1566.6	10.4	0.67%	1537.0	1545.9	8.9	0.58%	1572.55	1536.99	-2.26%	1582.54	1545.92	-2.31%
		Utility Based (Coal)	4.11	1595.0	1559.3	-35.6	-2.23%	1554.1	1552.5	-1.6	-0.10%	1553.3	1542.1	-11.1	-0.72%	1594.98	1553.25	-2.62%	1559.33	1542.12	-1.10%
		Utility Based High	4.11	1595.0	1559.3	-35.6	-2.23%	1557.5	1558.4	1.0	0.06%	1537.1	1543.6	6.4	0.42%	1594.98	1537.13	-3.63%	1559.33	1543.55	-1.01%
	ES(f)	Clear Sky w/Hg	4.15	845.8	847.1	1.3	0.16%	846.6	846.7	0.1	0.01%	838.5	833.5	-5.0	-0.59%	845.80	838.50	-0.86%	847.13	833.52	-1.61%
	2	Clear Sky wo/Hg	4.15	851.4	859.7	8.3	0.98%	828.1	834.6	6.5	0.79%	812.4	815.3	2.9	0.36%	851.35	812.44	-4.57%	859.66	815.34	-5.16%
		NAAQS	4.15	842.2	843.6	1.4	0.17%	829.0	828.3	-0.7	-0.09%	817.0	817.1	0.1	0.02%	842.19	817.00	-2.99%	843.60	817.15	-3.14%
		Utility Based (Coal)	4.15	835.3	825.4	-9.9	-1.18%	808.7	813.9	5.2	0.64%	793.5	790.0	-3.5	-0.44%	835.26	793.49	-5.00%	825.37	789.97	-4.29%
		Utility Based High	4.15	835.3	825.4	-9.9	-1.18%	804.5	802.5	-2.0	-0.25%	782.3	777.5	-4.7	-0.61%	835.26	782.27	-6.34%	825.37	777.53	-5.80%
	P(s)	Clear Sky w/Hg	6.20	5767.1	5770.6	3.5	0.06%	5734.8	5725.3	-9.5	-0.16%	5720.5	5727.3	6.8	0.12%	5767.15	5720.48	-0.81%	5770.64	5727.32	-0.75%
	3	Clear Sky wo/Hg	6.20	5728.4	5710.4	-18.0	-0.31%	5712.7	5700.6	-12.0	-0.21%	5645.6	5699.5	53.9	0.95%	5728.40	5645.61	-1.45%	5710.42	5699.51	-0.19%
		NAAQS	6.20	5761.2	5829.2	68.0	1.18%	5748.3	5715.7	-32.6	-0.57%	5694.3	5691.9	-2.3	-0.04%	5761.18	5694.26	-1.16%	5829.22	5691.93	-2.36%
		Utility Based (Coal)	6.20	5709.2	5706.8	-2.3	-0.04%	5646.6	5652.9	6.4	0.11%	5623.5	5628.6	5.1	0.09%	5709.17	5623.47	-1.50%	5706.84	5628.56	-1.37%
		Utility Based High	6.20	5709.2	5706.8	-2.3	-0.04%	5638.3	5631.9	-6.4	-0.11%	5667.6	5598.2	-69.5	-1.23%	5709.17	5667.65	-0.73%	5706.84	5598.18	-1.90%
	P(l)	Clear Sky w/Hg	5.28	7582.2	7549.5	-32.7	-0.43%	7347.5	7350.7	3.3	0.04%	7256.6	7293.5	37.0	0.51%	7582.25	7256.58	-4.30%	7549.52	7293.54	-3.39%
	4	Clear Sky wo/Hg	5.28	7483.3	7647.7	164.5	2.20%	7103.5	7174.5	70.9	1.00%	6831.3	6892.0	60.7	0.89%	7483.25	6831.31	-8.71%	7647.75	6892.01	-9.88%
		NAAQS	5.28	7424.1	7428.1	4.0	0.05%	7090.3	7127.5	37.2	0.52%	6880.5	6942.9	62.4	0.91%	7424.11	6880.48	-7.32%	7428.12	6942.93	-6.52%
		Utility Based (Coal)	5.28	7265.1	7009.3	-255.8	-3.52%	6734.8	6773.3	38.5	0.57%	6445.8	6392.5	-53.3	-0.83%	7265.09	6445.76	-11.28%	7009.31	6392.50	-8.80%
		Utility Based High	5.28	7265.1	7009.3	-255.8	-3.52%	6524.7	6584.4	59.7	0.91%	6207.8	6168.0	-39.9	-0.64%	7265.09	6207.82	-14.55%	7009.31	6167.95	-12.00%
	FD(l)	Clear Sky w/Hg	5.27	7348.8	7298.9	-49.8	-0.68%	7153.4	7198.9	45.6	0.64%	7003.9	7034.3	30.4	0.43%	7348.79	7003.92	-4.69%	7298.95	7034.33	-3.63%
	6	Clear Sky wo/Hg	5.27	7409.5	7656.3	246.8	3.33%	6889.9	7036.3	146.4	2.12%	6655.8	6597.4	-58.4	-0.88%	7409.46	6655.82	-10.17%	7656.29	6597.43	-13.83%
		NAAQS	5.27	7250.8	7277.6	26.8	0.37%	6989.4	7021.7	32.3	0.46%	6621.7	6674.6	52.9	0.80%	7250.77	6621.70	-8.68%	7277.61	6674.55	-8.23%
		Utility Based (Coal)	5.27	7179.2	6876.9	-302.2	-4.21%	6498.0	6631.5	133.5	2.05%	6192.2	6102.5	-89.7	-1.45%	7179.16	6192.22	-13.75%	6876.94	6102.54	-11.26%
		Utility Based High	5.27	7179.2	6876.9	-302.2	-4.21%	6459.2	6444.5	-14.7	-0.23%	5973.1	5920.7	-52.4	-0.88%	7179.16	5973.06	-16.80%	6876.94	5920.68	-13.91%
	S(s)	Clear Sky w/Hg	6.87	3553.4	3554.7	1.3	0.04%	3520.3	3510.5	-9.8	-0.28%	3511.9	3487.6	-24.3	-0.69%	3553.44	3511.94	-1.17%	3554.69	3487.62	-1.89%
	7	Clear Sky wo/Hg	6.87	3471.6	3505.6	34.0	0.98%	3494.2	3473.8	-20.4	-0.58%	3434.6	3447.2	12.6	0.37%	3471.59	3434.62	-1.06%	3505.57	3447.19	-1.67%
		NAAQS	6.87	3576.7	3565.9	-10.8	-0.30%	3457.5	3460.4	3.0	0.09%	3452.0	3411.7	-40.3	-1.17%	3576.73	3452.04	-3.49%	3565.92	3411.73	-4.32%
		Utility Based (Coal)	6.87	3541.1	3538.2	-2.9	-0.08%	3435.6	3419.7	-15.9	-0.46%	3390.5	3362.9	-27.6	-0.82%	3541.09	3390.50	-4.25%	3538.22	3362.87	-4.96%
		Utility Based High	6.87	3541.1	3538.2	-2.9	-0.08%	3367.7	3397.3	29.6	0.88%	3391.7	3356.1	-35.6	-1.05%	3541.09	3391.70	-4.22%	3538.22	3356.06	-5.15%
	S(l)	Clear Sky w/Hg	5.26	7770.1	7645.5	-124.6	-1.60%	7701.9	7723.3	21.4	0.28%	7478.9	7504.0	25.1	0.34%	7770.12	7478.91	-3.75%	7645.53	7503.98	-1.85%
	8	Clear Sky wo/Hg	5.26	7615.9	7659.4	43.6	0.57%	7384.9	7367.5	-17.4	-0.24%	7106.0	7145.7	39.7	0.56%	7615.87	7106.01	-6.69%	7659.42	7145.74	-6.71%
		NAAQS	5.26	7635.5	7683.8	48.3	0.63%	7493.9	7444.1	-49.8	-0.66%	7093.9	7116.7	22.8	0.32%	7635.49	7093.90	-7.09%	7683.79	7116.72	-7.38%
		Utility Based (Coal)	5.26	7381.9	7379.2	-2.7	-0.04%	7043.0	6996.4	-46.6	-0.66%	6698.0	6681.7	-16.3	-0.24%	7381.87	6698.05	-9.26%	7379.21	6681.72	-9.45%
		Utility Based High	5.26	7381.9	7379.2	-2.7	-0.04%	6885.7	6898.7	13.0	0.19%	6550.1	6499.3	-50.8	-0.78%	7381.87	6550.13	-11.27%	7379.21	6499.29	-11.92%
	SB(s)	Clear Sky w/Hg	5.36	51.4	50.6	-0.8	-1.59%	49.2	49.8	0.6	1.26%	50.6	51.2	0.6	1.09%	51.44	50.64	-1.55%	50.62	51.19	1.14%
	14	Clear Sky wo/Hg	5.36	52.9	51.5	-1.4	-2.74%	45.7	44.3	-1.4	-3.07%	42.8	42.7	0.0	-0.10%	52.92	42.79	-19.15%	51.48	42.74	-18.36%
		NAAQS	5.36	50.3	50.7	0.3	0.66%	46.2	46.8	0.6	1.26%	45.3	44.5	-0.8	-1.69%	50.33	45.31	-9.98%	50.66	44.54	-12.08%
		Utility Based (Coal)	5.36	50.5	46.3	-4.2	-8.38%	46.3	46.7	0.3	0.66%	42.5	43.1	0.6	1.47%	50.55	42.51	-15.91%	46.31	43.13	-6.87%
		Utility Based High	5.36	50.5	46.3	-4.2	-8.38%	46.4	45.9	-0.5	-1.01%	41.2	42.4	1.3	3.07%	50.55	41.15	-18.59%	46.31	42.42	-8.41%

TABLE 18
Meldahl Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Meldahl	ES(s)	Clear Sky w/Hg	7.60	2942.3	2939.6	-2.7	-0.09%	2933.7	2937.8	4.1	0.14%	2909.7	2909.3	-0.4	-0.01%	2942.27	2909.69	-1.11%	2939.56	2909.31	-1.03%
	1	Clear Sky wo/Hg	7.60	2928.7	2933.7	5.1	0.17%	2885.5	2920.0	34.6	1.20%	2850.9	2868.8	17.9	0.63%	2928.66	2850.90	-2.65%	2933.75	2868.76	-2.22%
		NAAQS	7.60	2948.9	2926.7	-22.2	-0.75%	2905.5	2918.3	12.8	0.44%	2849.6	2878.2	28.6	1.00%	2948.88	2849.60	-3.37%	2926.68	2878.17	-1.66%
		Utility Based (Coal)	7.60	2948.9	2888.5	-60.4	-2.05%	2878.6	2889.6	11.0	0.38%	2879.5	2848.3	-31.2	-1.08%	2948.88	2879.50	-2.35%	2888.45	2848.30	-1.39%
		Utility Based High	7.60	2948.9	2888.5	-60.4	-2.05%	2878.8	2873.8	-5.0	-0.17%	2859.3	2878.8	19.5	0.68%	2948.88	2859.30	-3.04%	2888.45	2878.80	-0.33%
	ES(f)	Clear Sky w/Hg	8.70	1727.9	1728.3	0.5	0.03%	1717.4	1718.5	1.1	0.06%	1706.9	1697.6	-9.3	-0.54%	1727.86	1706.89	-1.21%	1728.31	1697.59	-1.78%
	2	Clear Sky wo/Hg	8.70	1745.9	1767.6	21.7	1.24%	1674.5	1702.3	27.7	1.66%	1641.0	1648.5	7.5	0.46%	1745.86	1640.97	-6.01%	1767.55	1648.51	-6.74%
		NAAQS	8.70	1727.3	1714.6	-12.7	-0.74%	1672.5	1668.5	-3.9	-0.24%	1652.5	1670.5	17.9	1.08%	1727.34	1652.52	-4.33%	1714.59	1670.45	-2.57%
		Utility Based (Coal)	8.70	1703.4	1677.7	-25.7	-1.51%	1622.6	1636.7	14.1	0.87%	1591.7	1582.4	-9.2	-0.58%	1703.42	1591.67	-6.56%	1677.70	1582.45	-5.66%
		Utility Based High	8.70	1703.4	1677.7	-25.7	-1.51%	1622.4	1623.7	1.3	0.08%	1554.9	1551.1	-3.8	-0.24%	1703.42	1554.88	-8.72%	1677.70	1551.12	-7.54%
	P(s)	Clear Sky w/Hg	9.16	9039.6	9061.4	21.8	0.24%	9000.5	8994.6	-5.9	-0.07%	8957.4	8963.3	5.9	0.07%	9039.58	8957.40	-0.91%	9061.41	8963.29	-1.08%
	3	Clear Sky wo/Hg	9.16	9040.4	8980.3	-60.1	-0.66%	8984.0	8990.8	6.8	0.08%	8899.9	8947.3	47.5	0.53%	9040.40	8899.86	-1.55%	8980.29	8947.33	-0.37%
		NAAQS	9.16	9038.1	9081.6	43.5	0.48%	8976.0	8938.2	-37.8	-0.42%	8897.8	8863.2	-34.6	-0.39%	9038.07	8897.82	-1.55%	9081.56	8863.17	-2.40%
		Utility Based (Coal)	9.16	9055.3	9046.1	-9.3	-0.10%	8977.5	8968.3	-9.3	-0.10%	8898.5	8883.0	-15.5	-0.17%	9055.35	8898.52	-1.73%	9046.06	8883.02	-1.80%
		Utility Based High	9.16	9055.3	9046.1	-9.3	-0.10%	8915.4	8893.9	-21.5	-0.24%	8900.3	8924.7	24.4	0.27%	9055.35	8900.28	-1.71%	9046.06	8924.67	-1.34%
	P(f)	Clear Sky w/Hg	9.16	13494.4	13721.2	226.7	1.68%	13525.3	13505.7	-19.6	-0.15%	13057.2	12911.2	-146.0	-1.12%	13494.43	13057.20	-3.24%	13721.17	12911.21	-5.90%
	4	Clear Sky wo/Hg	9.16	13604.1	13363.5	-240.6	-1.77%	13070.2	13055.1	-15.1	-0.12%	12538.2	12610.8	72.6	0.58%	13604.14	12538.17	-7.84%	13363.53	12610.81	-5.63%
		NAAQS	9.16	13595.5	13750.1	154.6	1.14%	13253.5	13194.9	-58.7	-0.44%	12529.2	12449.5	-79.7	-0.64%	13595.48	12529.18	-7.84%	13750.10	12449.52	-9.46%
		Utility Based (Coal)	9.16	12734.3	12795.4	61.1	0.48%	12163.0	12066.8	-96.2	-0.79%	11708.3	11626.0	-82.3	-0.70%	12734.32	11708.32	-8.06%	12795.44	11626.03	-9.14%
		Utility Based High	9.16	12734.3	12795.4	61.1	0.48%	12016.4	12006.3	-10.1	-0.08%	11206.1	11015.5	-190.5	-1.70%	12734.32	11206.08	-12.00%	12795.44	11015.54	-13.91%
	FD(f)	Clear Sky w/Hg	9.15	13811.6	13631.6	-179.9	-1.30%	13574.3	13705.2	130.9	0.96%	12930.0	13056.9	126.9	0.98%	13811.57	12930.00	-6.38%	13631.64	13056.90	-4.22%
	6	Clear Sky wo/Hg	9.15	13213.0	13639.4	426.4	3.23%	13055.2	13059.9	4.7	0.04%	12531.2	12597.4	66.2	0.53%	13212.96	12531.19	-5.16%	13639.39	12597.38	-7.64%
		NAAQS	9.15	13526.2	13256.3	-270.0	-2.00%	13216.2	13275.7	59.5	0.45%	12502.4	12708.5	206.2	1.65%	13526.22	12502.38	-7.57%	13256.26	12708.54	-4.13%
		Utility Based (Coal)	9.15	12933.0	12554.8	-378.2	-2.92%	12043.5	12048.0	4.5	0.04%	11421.2	11429.0	7.8	0.07%	12933.01	11421.24	-11.69%	12554.77	11429.04	-8.97%
		Utility Based High	9.15	12933.0	12554.8	-378.2	-2.92%	11991.4	11881.1	-110.3	-0.92%	11269.8	10982.6	-287.3	-2.55%	12933.01	11269.82	-12.86%	12554.77	10982.55	-12.62%
	S(s)	Clear Sky w/Hg	8.81	5144.0	5129.3	-14.8	-0.29%	5103.5	5089.7	-13.9	-0.27%	5067.0	5045.1	-21.9	-0.43%	5144.03	5066.99	-1.50%	5129.27	5045.10	-1.64%
	7	Clear Sky wo/Hg	8.81	5069.2	5078.0	8.8	0.17%	5077.1	5066.8	-10.3	-0.20%	5014.4	4993.5	-20.8	-0.42%	5069.20	5014.36	-1.08%	5077.96	4993.53	-1.66%
		NAAQS	8.81	5108.4	5153.2	44.8	0.88%	5061.9	5056.1	-5.8	-0.11%	5037.3	4983.7	-53.6	-1.06%	5108.42	5037.32	-1.39%	5153.18	4983.74	-3.29%
		Utility Based (Coal)	8.81	5125.8	5140.1	14.4	0.28%	5033.6	5034.0	0.4	0.01%	4955.3	4957.4	2.1	0.04%	5125.78	4955.29	-3.33%	5140.15	4957.35	-3.58%
		Utility Based High	8.81	5125.8	5140.1	14.4	0.28%	4968.6	4950.1	-18.4	-0.37%	4947.9	4931.4	-16.4	-0.33%	5125.78	4947.85	-3.47%	5140.15	4931.42	-4.06%
	S(f)	Clear Sky w/Hg	9.13	14052.0	13890.8	-161.2	-1.15%	14027.3	14050.0	22.7	0.16%	13365.1	13359.2	-5.9	-0.04%	14051.98	13365.09	-4.89%	13890.80	13359.23	-3.83%
	8	Clear Sky wo/Hg	9.13	13870.4	13850.1	-20.3	-0.15%	13471.0	13405.3	-65.7	-0.49%	12995.9	12993.5	-2.5	-0.02%	13870.40	12995.93	-6.30%	13850.09	12993.47	-6.18%
		NAAQS	9.13	13984.6	13986.2	1.6	0.01%	13559.6	13387.3	-172.3	-1.27%	12910.0	12887.8	-22.2	-0.17%	13984.63	12909.96	-7.68%	13986.19	12887.78	-7.85%
		Utility Based (Coal)	9.13	13314.3	13087.2	-227.1	-1.71%	12729.1	12553.4	-175.7	-1.38%	11953.3	11871.8	-81.5	-0.68%	13314.29	11953.31	-10.22%	13087.17	11871.78	-9.29%
		Utility Based High	9.13	13314.3	13087.2	-227.1	-1.71%	12283.8	12281.8	-2.0	-0.02%	11659.6	11642.7	-16.8	-0.14%	13314.29	11659.56	-12.43%	13087.17	11642.71	-11.04%
	SB(s)	Clear Sky w/Hg	4.98	53.9	52.4	-1.4	-2.69%	52.8	53.5	0.7	1.26%	53.2	53.6	0.4	0.76%	53.88	53.20	-1.28%	52.44	53.60	2.23%
	14	Clear Sky wo/Hg	4.98	51.7	52.6	0.8	1.62%	49.1	48.7	-0.4	-0.82%	45.7	47.0	1.3	2.77%	51.74	45.69	-11.70%	52.58	46.95	-10.70%
		NAAQS	4.98	50.8	50.9	0.2	0.35%	49.2	49.4	0.2	0.42%	46.6	48.1	1.4	3.05%	50.77	46.63	-8.15%	50.95	48.06	-5.68%
		Utility Based (Coal)	4.98	49.2	47.6	-1.6	-3.29%	46.4	46.6	0.2	0.48%	43.9	43.8	-0.1	-0.23%	49.22	43.88	-10.85%	47.61	43.78	-8.04%
		Utility Based High	4.98	49.2	47.6	-1.6	-3.29%	45.8	46.5	0.7	1.55%	44.2	43.4	-0.8	-1.85%	49.22	44.20	-10.20%	47.61	43.39	-8.86%

TABLE 19
Markland Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Markland	ES(s)	Clear Sky w/Hg	9.45	3795.9	3791.5	-4.4	-0.12%	3775.7	3782.9	7.2	0.19%	3762.2	3744.8	-17.5	-0.46%	3795.88	3762.23	-0.89%	3791.47	3744.76	-1.23%
	1	Clear Sky wo/Hg	9.45	3788.9	3780.9	-8.0	-0.21%	3744.2	3775.1	30.9	0.83%	3706.9	3713.6	6.7	0.18%	3788.92	3706.91	-2.16%	3780.90	3713.58	-1.78%
		NAAQS	9.45	3786.6	3779.9	-6.7	-0.18%	3754.3	3766.6	12.3	0.33%	3714.4	3722.6	8.2	0.22%	3786.63	3714.39	-1.91%	3779.91	3722.64	-1.52%
		Utility Based (Coal)	9.45	3780.4	3737.7	-42.7	-1.13%	3728.6	3731.0	2.5	0.07%	3728.0	3696.0	-32.0	-0.86%	3780.42	3728.01	-1.39%	3737.68	3695.99	-1.12%
		Utility Based High	9.45	3780.4	3737.7	-42.7	-1.13%	3733.7	3720.6	-13.1	-0.35%	3696.5	3716.1	19.6	0.53%	3780.42	3696.54	-2.22%	3737.68	3716.10	-0.58%
	ES(f)	Clear Sky w/Hg	12.18	2455.5	2455.4	-0.1	0.00%	2418.8	2419.1	0.2	0.01%	2392.9	2388.4	-4.6	-0.19%	2455.51	2392.94	-2.55%	2455.44	2388.39	-2.73%
	2	Clear Sky wo/Hg	12.18	2436.5	2491.3	54.8	2.25%	2357.6	2406.7	49.1	2.08%	2333.4	2349.8	16.4	0.70%	2436.49	2333.43	-4.23%	2491.26	2349.84	-5.68%
		NAAQS	12.18	2455.4	2440.2	-15.2	-0.62%	2366.9	2374.3	7.4	0.31%	2352.8	2381.7	28.9	1.23%	2455.39	2352.83	-4.18%	2440.19	2381.70	-2.40%
		Utility Based (Coal)	12.18	2433.3	2395.2	-38.1	-1.57%	2321.0	2351.4	30.4	1.31%	2297.7	2271.3	-26.4	-1.15%	2433.33	2297.66	-5.58%	2395.23	2271.30	-5.17%
		Utility Based High	12.18	2433.3	2395.2	-38.1	-1.57%	2342.8	2367.4	24.6	1.05%	2255.8	2286.8	31.0	1.38%	2433.33	2255.80	-7.30%	2395.23	2286.84	-4.53%
	P(s)	Clear Sky w/Hg	10.12	10664.9	10644.4	-20.5	-0.19%	10615.7	10613.4	-3.4	-0.03%	10586.4	10598.9	12.4	0.12%	10664.90	10586.44	-0.74%	10644.43	10598.86	-0.43%
	3	Clear Sky wo/Hg	10.12	10662.1	10618.1	-44.0	-0.41%	10617.5	10616.0	-1.5	-0.01%	10528.0	10571.6	43.6	0.41%	10662.12	10527.99	-1.26%	10618.08	10571.58	-0.44%
		NAAQS	10.12	10665.9	10703.9	38.0	0.36%	10615.4	10576.4	-39.0	-0.37%	10569.9	10511.7	-58.3	-0.55%	10665.93	10569.93	-0.90%	10703.90	10511.65	-1.80%
		Utility Based (Coal)	10.12	10675.2	10668.2	-7.0	-0.07%	10599.6	10615.4	15.8	0.15%	10547.6	10525.5	-22.1	-0.21%	10675.19	10547.64	-1.19%	10668.20	10525.51	-1.34%
		Utility Based High	10.12	10675.2	10668.2	-7.0	-0.07%	10573.5	10531.7	-41.8	-0.40%	10529.3	10535.0	5.7	0.05%	10675.19	10529.28	-1.37%	10668.20	10535.02	-1.25%
	P(l)	Clear Sky w/Hg	9.49	14269.3	14485.0	215.7	1.51%	14059.7	14048.2	-11.5	-0.08%	13518.8	13304.5	-214.3	-1.59%	14269.29	13518.84	-5.28%	14484.98	13304.52	-8.15%
	4	Clear Sky wo/Hg	9.49	14187.8	13979.0	-208.8	-1.47%	13609.7	13659.2	49.4	0.36%	13127.2	13220.9	93.7	0.71%	14187.84	13127.23	-7.48%	13979.02	13220.95	-5.42%
		NAAQS	9.49	14266.3	14459.9	193.6	1.36%	13875.6	13756.2	-119.4	-0.86%	13115.4	12955.2	-160.2	-1.22%	14266.27	13115.41	-8.07%	14459.89	12955.20	-10.41%
		Utility Based (Coal)	9.49	13430.3	13631.4	201.1	1.50%	13125.1	13007.5	-117.7	-0.90%	12580.7	12598.9	18.2	0.14%	13430.31	12580.73	-6.33%	13631.45	12598.95	-7.57%
		Utility Based High	9.49	13430.3	13631.4	201.1	1.50%	12948.6	12941.6	-7.0	-0.05%	12201.9	11963.3	-238.6	-1.96%	13430.31	12201.93	-9.15%	13631.45	11963.33	-12.24%
	FD(l)	Clear Sky w/Hg	9.48	14287.5	14433.8	146.3	1.02%	13955.8	14117.1	161.2	1.16%	13434.2	13412.8	-21.4	-0.16%	14287.51	13434.19	-5.97%	14433.78	13412.76	-7.07%
	6	Clear Sky wo/Hg	9.48	13864.8	14258.2	393.4	2.84%	13651.3	13737.4	86.1	0.63%	13128.7	13217.9	89.2	0.68%	13864.82	13128.70	-5.31%	14258.18	13217.93	-7.30%
		NAAQS	9.48	14189.2	14090.0	-99.2	-0.70%	13794.8	13898.5	103.7	0.75%	13074.7	13083.3	8.6	0.07%	14189.23	13074.67	-7.86%	14090.03	13083.30	-7.14%
		Utility Based (Coal)	9.48	13745.7	13329.9	-415.8	-3.02%	13011.6	13060.8	49.3	0.38%	12393.1	12445.4	52.3	0.42%	13745.70	12393.14	-9.84%	13329.92	12445.41	-6.64%
		Utility Based High	9.48	13745.7	13329.9	-415.8	-3.02%	13023.4	12953.7	-69.6	-0.53%	12268.6	11969.0	-299.7	-2.44%	13745.70	12268.65	-10.72%	13329.92	11968.97	-10.21%
	S(s)	Clear Sky w/Hg	12.01	7364.7	7380.4	15.7	0.21%	7293.7	7286.1	-7.6	-0.10%	7240.7	7207.8	-32.9	-0.45%	7364.74	7240.73	-1.68%	7380.44	7207.79	-2.34%
	7	Clear Sky wo/Hg	12.01	7272.8	7304.7	31.9	0.44%	7242.5	7223.5	-18.9	-0.26%	7168.6	7142.4	-26.3	-0.37%	7272.82	7168.64	-1.43%	7304.74	7142.36	-2.22%
		NAAQS	12.01	7335.7	7381.9	46.2	0.63%	7277.9	7249.9	-28.0	-0.38%	7211.0	7157.4	-53.6	-0.74%	7335.67	7211.03	-1.70%	7381.86	7157.44	-3.04%
		Utility Based (Coal)	12.01	7345.1	7369.7	24.6	0.34%	7213.4	7226.6	13.1	0.18%	7147.0	7111.9	-35.2	-0.49%	7345.11	7147.04	-2.70%	7369.73	7111.88	-3.50%
		Utility Based High	12.01	7345.1	7369.7	24.6	0.34%	7114.6	7107.3	-7.3	-0.10%	7084.7	7095.5	10.8	0.15%	7345.11	7084.65	-3.55%	7369.73	7095.48	-3.72%
	S(l)	Clear Sky w/Hg	9.45	14867.6	14861.1	-6.5	-0.04%	14488.9	14502.6	13.7	0.09%	13852.0	13895.2	43.2	0.31%	14867.57	13852.02	-6.83%	14861.08	13895.17	-6.50%
	8	Clear Sky wo/Hg	9.45	14608.5	14647.7	39.2	0.27%	14128.3	14114.2	-14.1	-0.10%	13501.2	13608.3	107.1	0.79%	14608.47	13501.24	-7.58%	14647.70	13608.30	-7.10%
		NAAQS	9.45	14698.6	14819.7	121.1	0.82%	14126.7	13927.0	-199.6	-1.41%	13409.7	13499.0	89.3	0.67%	14698.58	13409.74	-8.77%	14819.66	13499.01	-8.91%
		Utility Based (Coal)	9.45	14177.0	13908.9	-268.1	-1.89%	13541.5	13458.9	-82.5	-0.61%	12912.6	12846.0	-66.6	-0.52%	14177.02	12912.59	-8.89%	13908.95	12846.03	-7.64%
		Utility Based High	9.45	14177.0	13908.9	-268.1	-1.89%	13236.2	13271.1	34.9	0.26%	12720.4	12655.2	-65.2	-0.51%	14177.02	12720.40	-10.27%	13908.95	12655.24	-9.01%
	SB(s)	Clear Sky w/Hg	13.31	195.1	196.5	1.4	0.70%	196.2	198.2	2.0	1.00%	191.3	194.0	2.8	1.45%	195.15	191.27	-1.99%	196.50	194.04	-1.25%
	14	Clear Sky wo/Hg	13.31	194.9	198.2	3.2	1.66%	187.9	187.5	-0.4	-0.20%	177.9	182.6	4.8	2.68%	194.94	177.85	-8.77%	198.17	182.62	-7.86%
		NAAQS	13.31	193.8	198.2	4.4	2.26%	182.7	184.3	1.6	0.88%	179.8	183.2	3.4	1.89%	193.80	179.82	-7.21%	198.18	183.22	-7.55%
		Utility Based (Coal)	13.31	184.5	176.5	-8.0	-4.33%	176.8	182.9	6.2	3.48%	171.7	171.8	0.0	0.02%	184.48	171.72	-6.91%	176.49	171.75	-2.68%
		Utility Based High	13.31	184.5	176.5	-8.0	-4.33%	176.8	177.3	0.5	0.27%	172.8	171.2	-1.6	-0.95%	184.48	172.85	-6.31%	176.49	171.21	-2.99%

TABLE 20
McAlpine Pool
NAVSAT Data

Pool	Fish Species/ Life Stage	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070		2010-2070	
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
McAlpine	ES(s)	Clear Sky w/Hg	7.617776	2707.24563	2701.246	-6.0	-0.22%	2670.76228	2693.64528	12.9	0.48%	2649.95438	2639.51699	-11.3	-0.43%	2707.25	2649.95	-2.12%	2701.25	2639.52	-2.32%
	1	Clear Sky wo/Hg	7.617776	2690.45445	2693.24655	2.8	0.10%	2648.94898	2669.83763	20.9	0.78%	2614.1629	2614.31839	0.2	0.01%	2690.45	2614.16	-2.84%	2693.25	2614.32	-2.93%
		NAAQS	7.617776	2693.7275	2690.3329	6.6	0.25%	2643.06945	2657.80303	14.7	0.56%	2605.85983	2606.19373	5.5	0.21%	2693.73	2605.86	-3.22%	2690.33	2606.19	-3.12%
		Utility Based (Coal)	7.617776	2694.50165	2645.54863	-49.0	-1.82%	2644.09968	2633.06358	-11.0	-0.42%	2622.49413	2593.18945	-29.3	-1.12%	2694.50	2622.49	-2.67%	2645.55	2593.19	-1.98%
		Utility Based Hwd	7.617776	2694.50165	2645.54863	-49.0	-1.82%	2647.95713	2629.48405	-18.5	-0.70%	2617.62578	2637.8174	20.2	0.77%	2694.50	2617.63	-2.95%	2645.55	2637.82	-0.29%
	ES(f)	Clear Sky w/Hg	8.528969	1714.32583	1713.9015	-0.4	-0.02%	1676.63203	1674.43483	-2.2	-0.13%	1650.92353	1654.3847	3.5	0.21%	1714.33	1650.92	-3.69%	1713.90	1654.38	-3.47%
	2	Clear Sky wo/Hg	8.528969	1700.6355	1720.5528	19.9	1.17%	1647.30963	1667.4259	40.1	2.44%	1649.6577	1662.74143	12.9	0.78%	1700.64	1649.84	-2.99%	1720.55	1662.74	-3.36%
		NAAQS	8.528969	1734.74817	1703.35277	-21.4	-1.24%	1668.7108	1670.12183	10.4	0.63%	1650.75527	1683.22303	12.5	0.76%	1734.75	1650.76	-4.82%	1703.35	1683.22	-2.36%
		Utility Based (Coal)	8.528969	1710.81653	1692.9425	-17.9	-1.04%	1641.94263	1672.0748	30.1	1.84%	1643.7716	1650.57453	-13.2	-0.80%	1710.82	1643.77	-3.90%	1692.94	1650.57	-2.50%
		Utility Based Hwd	8.528969	1710.81653	1692.9425	-17.9	-1.04%	1648.87423	1661.38677	14.7	0.89%	1618.70543	1650.4152	31.7	1.96%	1710.82	1618.71	-5.36%	1692.94	1650.42	-2.51%
	P(s)	Clear Sky w/Hg	10.635525	10643.6333	10586.9745	-56.7	-0.53%	10468.5333	10453.88	-4.7	-0.04%	10445.8013	10460.1083	14.3	0.14%	10643.63	10445.80	-1.86%	10586.97	10460.11	-1.20%
	3	Clear Sky wo/Hg	10.635525	10557.541	10586.3045	9.7	0.08%	10537.725	10517.654	-20.1	-0.19%	10375.3585	10440.709	65.3	0.63%	10557.54	10375.36	-1.73%	10586.30	10440.71	-1.19%
		NAAQS	10.635525	10596.2443	10635.2483	39.0	0.37%	10528.8975	10474.636	-54.3	-0.52%	10416.5365	10371.574	-45.0	-0.43%	10596.24	10416.54	-1.70%	10635.25	10371.57	-2.48%
		Utility Based (Coal)	10.635525	10619.3755	10597.9665	-21.4	-0.20%	10513.1033	10550.9483	37.8	0.36%	10450.384	10461.5585	11.2	0.11%	10619.38	10450.38	-1.58%	10597.97	10461.54	-1.29%
		Utility Based Hwd	10.635525	10619.3755	10597.9665	-21.4	-0.20%	10514.2125	10462.1288	-52.1	-0.50%	10431.6613	10434.498	2.8	0.03%	10619.38	10431.66	-1.77%	10597.97	10434.50	-1.54%
	P(l)	Clear Sky w/Hg	8.891487	13826.9806	13912.5002	85.5	0.62%	13386.3644	13385.5816	-0.8	-0.01%	13110.389	13013.8128	-96.6	-0.74%	13826.98	13110.39	-5.16%	13912.50	13013.81	-6.46%
	4	Clear Sky wo/Hg	8.891487	13790.1618	13750.5599	-39.6	-0.29%	13387.7248	13486.9288	79.2	0.59%	13098.3884	13128.0988	29.1	0.22%	13790.16	13098.39	-5.01%	13750.56	13128.09	-4.52%
		NAAQS	8.891487	13749.859	13900.2198	150.4	1.09%	13802.734	13429.8244	-172.9	-1.27%	12979.4636	12807.449	-172.0	-1.33%	13749.86	12979.46	-5.63%	13900.22	12807.45	-7.88%
		Utility Based (Coal)	8.891487	13800.4038	13717.093	116.7	0.86%	13225.2234	13200.4296	-24.8	-0.19%	12955.5172	13008.433	52.9	0.41%	13800.40	12955.52	-6.11%	13717.08	13008.43	-5.17%
		Utility Based Hwd	8.891487	13800.4038	13717.093	116.7	0.86%	13089.8724	13190.2528	100.4	0.77%	12571.473	12628.9086	57.4	0.46%	13800.40	12571.47	-8.90%	13717.08	12628.91	-7.96%
		Clear Sky w/Hg		11212.2366	11211.1434	-1.1	-0.01%	11192.4358	11191.9114	-0.5	0.00%	11189.5366	11189.4954	0.2	0.00%	11212.24	11189.51	-0.20%	11211.14	11189.49	-0.19%
	6	Clear Sky wo/Hg		11209.4682	11213.0262	2.5	0.02%	11200.5222	11198.9464	-0.7	-0.01%	11191.8242	11188.3588	-3.3	-0.03%	11209.50	11191.82	-0.16%	11213.03	11188.36	-0.21%
		NAAQS		11208.0804	11206.3942	-1.7	-0.02%	11198.8918	11197.029	-1.9	-0.02%	11193.9252	11190.7112	-3.2	-0.03%	11208.09	11193.93	-0.13%	11206.39	11190.71	-0.14%
		Utility Based (Coal)		11208.889	11203.3109	-3.6	-0.03%	11198.3846	11203.8348	5.5	0.05%	11202.8602	11196.4854	-6.4	-0.06%	11208.89	11202.86	-0.04%	11203.31	11196.49	-0.06%
		Utility Based Hwd		11208.889	11203.3108	-3.6	-0.03%	11200.3766	11200.1238	-0.3	0.00%	11193.4934	11194.2966	0.8	0.01%	11208.89	11193.49	-0.12%	11203.31	11194.30	-0.08%
	FD(l)	Clear Sky w/Hg	8.88	13843.6423	13944.572	100.9	0.73%	13330.7457	13426.203	95.5	0.72%	12909.8597	12916.1797	-90.7	-0.70%	13843.64	12909.86	-6.75%	13944.57	12916.18	-6.67%
	6	Clear Sky wo/Hg	8.88	13477.9657	13369.1417	391.2	2.92%	13420.3927	13490.678	70.3	0.52%	13008.2227	13116.6753	108.5	0.83%	13477.97	13008.22	-3.47%	13369.14	13116.68	-1.89%
		NAAQS	8.88	13594.8737	13665.5443	80.7	0.59%	13385.2423	13468.624	113.4	0.85%	12801.1927	12763.8037	-37.6	-0.29%	13594.87	12801.19	-5.84%	13665.54	12763.80	-5.62%
		Utility Based (Coal)	8.88	13852.2837	13589.6453	-262.6	-1.92%	13128.5707	13096.9963	-31.6	-0.24%	12866.296	12845.7907	-20.5	-0.16%	13852.28	12866.30	-7.26%	13589.65	12845.79	-5.48%
		Utility Based Hwd	8.88	13852.2837	13589.6453	-262.6	-1.92%	13174.4953	13280.9113	86.4	0.66%	12767.1797	12890.1917	-77.0	-0.60%	13852.28	12767.18	-8.47%	13589.65	12890.19	-5.48%
	S(s)	Clear Sky w/Hg	11.96	6784.19167	6752.87933	-31.4	-0.46%	6843.69	6815.63967	-28.1	-0.42%	6688.826	6633.54967	-33.3	-0.51%	6784.18	6688.83	-2.26%	6752.88	6633.55	-2.26%
	7	Clear Sky wo/Hg	11.96	6835.028	6842.643	7.6	0.12%	6600.11433	6510.57033	-89.5	-1.36%	6611.1887	6530.475	8.3	0.14%	6835.03	6611.19	-1.72%	6842.64	6530.48	-1.76%
		NAAQS	11.96	6709.81267	6810.42633	100.6	1.50%	6607.67533	6587.413	-20.3	-0.31%	6541.93233	6502.32433	-39.6	-0.61%	6709.81	6541.93	-2.50%	6810.43	6502.32	-3.77%
		Utility Based (Coal)	11.96	6727.67533	6744.83933	17.2	0.26%	6565.14933	6581.69667	16.7	0.26%	6505.28933	6524.378	19.1	0.29%	6727.68	6505.29	-3.31%	6744.84	6524.38	-3.27%
		Utility Based Hwd	11.96	6727.67533	6744.83933	17.2	0.26%	6539.35087	6512.78533	-26.6	-0.41%	6471.24833	6483.32733	12.1	0.19%	6727.68	6471.25	-3.81%	6744.84	6483.33	-3.86%
	S(l)	Clear Sky w/Hg	9.85	14329.1293	14282.9947	-66.1	-0.46%	13691.0273	13698.2033	-5.8	-0.04%	13324.139	13377.5597	53.3	0.40%	14329.12	13324.14	-7.02%	14282.99	13377.56	-6.33%
	8	Clear Sky wo/Hg	9.85	14163.0382	14295.1867	132.1	0.93%	13749.0962	13926.4632	177.4	1.29%	13316.5593	13494.5308	178.0	1.34%	14163.04	13316.56	-5.97%	14295.19	13494.53	-5.61%
		NAAQS	9.85	14191.2122	14317.1777	126.0	0.89%	13712.1202	13640.4728	-71.6	-0.52%	13092.4585	13223.4755	131.0	1.00%	14191.21	13092.46	-7.74%	14317.18	13223.48	-7.64%
		Utility Based (Coal)	9.85	14122.8287	13849.8337	-273.0	-1.93%	13529.152	13461.691	-67.5	-0.50%	13234.1303	13232.6533	-1.5	-0.01%	14122.83	13234.13	-6.27%	13849.83	13232.65	-4.45%
		Utility Based Hwd	9.85	14122.8287	13849.8337	-273.0	-1.93%	13436.411	13437.7582	1.3	0.01%	13092.134	13221.0725	128.9	0.98%	14122.83	13092.13	-7.30%	13849.83	13221.07	-4.54%
		Clear Sky w/Hg		917.94795	917.9437	0.0	0.00%	917.952225	917.9806	0.0	0.00%	917.901575	917.927525	0.0	0.00%	917.95	917.90	-0.01%	917.94	917.93	0.00%
	9	Clear Sky wo/Hg		917.8981	917.93955	0.1	0.01%	917.925425	917.94195	0.0	0.00%	917.92615	917.943875	0.0	0.00%	917.89	917.93	0.00%	917.94	917.94	0.00%
		NAAQS		917.95515	917.925	0.0	0.00%	917.93995	917.959975	0.0	0.00%	917.914	917.9158	0.0	0.00%	917.98	917.91	-0.01%	917.93	917.92	0.00%
		Utility Based (Coal)		917.9981	917.875925	-0.1	-0.01%	917.8992	917.9398	0.1	0.01%	917.907975	917.9258	0.0	0.00%	917.99	917.91	-0.01%	917.89	917.93	0.01%
		Utility Based Hwd		917.9981	917.875925	-0.1	-0.01%	917.93215	917.97585	0.0	0.01%	917.95485	917.94995	0.0	0.00%	917.99	917.95	0.00%	917.89	917.95	0.01%
		Clear Sky w/Hg		172.5911187	172.627437	0.1	0.07%	172.404607	172.469883	0.1	0.03%	173.49884	173.24791	-0.3	-0.14%	172.59	173.50	0.58%	172.63	173.25	0.36%
	10	Clear Sky wo/Hg		172.237533	172.4252	0.2	0.11%	173.32356	172.820453	-0.5	-0.29%	172.980553	172.542127	-0.4	-0.25%	172.24	172.98	0.43%	172.43	172.54	0.07%
		NAAQS		172.77442	172.43339	-0.3	-0.20%	171.77402	172.028603	0.3	0.15%	173.022313	172.664677	-0.4	-0.21%	172.77	173.02	0.14%	172.43	172.66	0.13%
		Utility Based (Coal)		172.677673	172.636967	0.0	-0.02%	171.852887	172.359987	0.5	0.30%	172.52752	172.16249	-0.3	-0.19%	172.68	172.53	-0.09%	172.64	172.19	-0.26%
		Utility Based Hwd		172.677673	172.636967	0.0	-0.02%	172.411787	172.726137	0.3	0.18%	172.555717	173.11449	0.6	0.32%	172.68	172.56	-0.07%	172.64	173.11	0.28%
		Clear Sky w/Hg		189.977343	189.84668	0.0	-0.07%	189.841403	189.849877	0.0	0.00%	189.021437	189.987883	0.0	0.00%	189.98	190.02	0.02%	189.85	189.99	0.07%
	11	Clear Sky wo/Hg		189.958327	189.85757	0.0	0.00%	189.89253	189.906993	-0.1	-0.05%	189.926993	189.870007	-0.1	-0.03%	189.96	189.93	0.04%	189.86	189.87	0.01%
		NAAQS		189.90584	189.842717	-0.1	-0.03%	189.740313	189.741617	0.0	0.00%	189.925313	189.999433	0.0	0.02%	189.91	189.93	0.01%	189.84	189.90	0.03%
		Utility Based (Coal)		189.89018	189.874363	0.0	-0.01%	189.798727	189.927823	0.0	0.02%	189.97817	189.974377	0.0	0.00%	189.99	189.88	-0.01%	189.87	189.97	0.00%
		Utility Based Hwd		189.89018	189.874363	0.0	-0.01%	189.814153	189.88346	0.1	0.04%	189.918137	189.972657	0.1	0.05%	189.99	189.92	0.01%	189.87	189.97	0.05%
		Clear Sky w/Hg		3225.45048	3225.30474	-0.1	0.00%	3224.57008	3224.64668	0.1	0.00%	3224.20048	3224.07964	-0.1	0.00%	3225.45	3224.20	-0.04%	3225.30	3224.08	-0.04%
	12	Clear Sky wo/Hg		3224.91998	3225.24942	0.3	0.01%	3224.80308	3224.73096	-0.2	-0.01%	3224.39348	3224.34018	-0.2	0.00%	3224.92	3224.39	-0.02%	3225.25	3224.24	-0.03%
		NAAQS		3224.90922	3225.18456	0.3	0.01%	3224.79746	3224.6388	-0.2	0.00%	3224.76502	3224.33178	-0.4	-0.01%	3224.91	3224.77	0.00%	3225.18	3224.33	-0.03%
		Utility Based (Coal)		3225.20708	3224.91982	-0.3	-0.01%	3225.14524	3225.20146	0.1	0.00%	3224.89026	3224.60486	-0.1	0.00%	3225.21	3224.89	-0.02%	3224.92	3224.60	-0.01%
		Utility Based Hwd		3225.20708	3224.91982	-0.3	-0.01%	3224.69678	3224.74406	-0.1	0.00%	3224.68982	3224.71756	0.0	0.00%	3225.21	3224.67	-0.02%	3224.92	3224.72	-0.01%
		Clear Sky w/Hg		4278.14234	4278.95633	-0.1	0.00%	4277.91284	4277.8153	0.0	0.00%	4277.40187	4277.34501	-0.1	0.00%	4278.14	4277.40	-0.04%	4278.00	4277.35	-0.04%
	13	Clear Sky wo/Hg		4278.70449	4278.68374	0.0	0.00%	4278.36594	4277.85261	-0.5	-0.01%	4277.70063	4277.73241	0.0	0.00%	4278.70	4277.70	-0.02%	4278.68	4277.73	-0.02%
		NAAQS		4278.43331	4278.80687	0.4	0.01%	4278.01547	4277.87469	-0.1	0.00%	4277.39156	4277.40614	0.0	0.00%	4278.43	4277.39	-0.02%	4278.81	4277.41	-0.03%
		Utility Based (Coal)		4278.43821	4278.54133	0.1	0.00%	4278.3274	4278.10123	-0.2	-0.01%	4277.91447	4277.67679	0.1	0.00%	4278.44	4277.61	-0.02%	4278.54	4277.68	-0.02%
		Utility Based Hwd		4278.43821	4278.54133	0.1	0.00%	4277.99955	4278.20281	0.2	0.01%	4277.44897	4277.42706	0.0	0.00%	4278.44	4277.45	-0.02%	4278.54	4277.43	-0.03%
	SB(s)	Clear Sky w/Hg	4.13	45.8097587	47.0993003	1.3	2.82%	45.8176507	46.7373153	0.8	1.79%	45.2572723	46.1305254	0.9	1.93%	45.81	45.26	-1.20%	47.10	46.13	-2.06%
	14	Clear Sky wo/Hg	4.13	47.5919827	48.502252	0.9	1.91%	46.4727143	45.3729197	-1.1	-2.37%	42.7344127	43.9439851	1.1	2.60%	47.59	42.73	-10.21%	48.50	43.94	-9.40%
		NAAQS	4.13	49.45978	49.1167657	-0.3	-0.69%	43.0315103	43.8468017	0.8	1.90%	41.6179847	43.7452953	2.1	5.11%	49.46	41.62	-15.85%	49.12	43.75	-10.94%
		Utility Based (Coal)	4.13	45.9836143	41.9755037	-4.0	-8.72%	43.0903137	43.265942	0.2	0.41%	40.8045453	41.18795	0.4	0.94%	45.98	40.80	-11.29%	41.98	41.19	-1.88%
		Utility Based Hwd	4.13	45.9836143	41.9755037	-4.0	-8.72%	42.6779113	42.7042103	0.1	0.30%	41.6736553	42.303795	0.6	1.51%	45.98	41.67	-9.36%	41.98	42.30	0.78%
		Clear Sky w/Hg		1636.40539	1636.3862	0.0	0.00%	1636.27777	1636.30987	0.0	0.00%	1636.28151	1636.26714	0.0	0.00%	1636.41	1636.28	-0.01%	1636.39	1636.27	-0.01%
	15	Clear Sky wo/Hg		1636.40688	1636.34651	-0.1	0.00%	1636.31284	1636.28847	0.0	0.00%	1636.2025	1636.27391	0.1	0.00%	1636.41	1636.20	-0.01%	1636.35	1636.27	0.00%
		NAAQS		1636.33883	1636.34893	0.0	0.00%	1636.25724	1636.27871	0.0	0.00%	1636.20946	1636.18581	0.0	0.00%	1636.34	1636.21	-0.01%	1636.35	1636.19	-0.01%
		Utility Based (Coal)		1636.39531	1636.35654	0.0	0.00%	1636.30697	1636.33177	0.0	0.00%	1636.26116	1636.28997	0.0	0.00%	1636.40	1636.26	-0.01%	1636.36	1636.29	0.00%
		Utility Based Hwd		1636.39531	1636.35654	0.0	0.00%	1636.31739	1636.31116	0.0	0.00%	1636.29507	1636.27029	0.0	0.00%	1636.40	1636.30	-0.01%	1636.36	1636.27	-0.01%

TABLE 21
Cannelton Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Cannelton	ES(s)	Clear Sky w/Hg	11.30	4336.0	4340.7	4.7	0.11%	4306.4	4301.9	-4.5	-0.10%	4295.5	4298.5	3.0	0.07%	4335.99	4295.45	-0.93%	4340.70	4298.48	-0.97%
	1	Clear Sky wo/Hg	11.30	4333.2	4328.9	-4.3	-0.10%	4299.4	4311.0	11.6	0.27%	4234.6	4272.3	37.7	0.89%	4333.20	4234.80	-2.28%	4328.92	4272.33	-1.31%
		NAAQS	11.30	4324.5	4346.2	21.8	0.50%	4318.8	4313.8	-5.0	-0.12%	4243.7	4243.3	-0.5	-0.01%	4324.45	4243.73	-1.87%	4346.21	4243.26	-2.37%
		Utility Based (Coal)	11.30	4327.2	4289.6	-37.6	-0.87%	4265.2	4274.1	8.8	0.21%	4253.9	4250.8	-3.1	-0.07%	4327.19	4253.92	-1.69%	4289.55	4250.82	-0.90%
		Utility Based High	11.30	4327.2	4289.6	-37.6	-0.87%	4299.7	4290.1	-9.5	-0.22%	4235.9	4260.7	24.8	0.59%	4327.19	4235.94	-2.11%	4289.55	4260.75	-0.67%
	ES(f)	Clear Sky w/Hg	5.71	1221.2	1213.6	-7.5	-0.62%	1204.4	1206.6	2.2	0.18%	1194.7	1193.4	-1.3	-0.11%	1221.16	1194.65	-2.17%	1213.61	1193.36	-1.67%
	2	Clear Sky wo/Hg	5.71	1209.6	1217.1	7.5	0.62%	1200.5	1211.9	11.4	0.95%	1188.7	1186.6	-2.2	-0.18%	1209.63	1188.74	-1.73%	1217.11	1186.58	-2.51%
		NAAQS	5.71	1219.5	1213.3	-6.2	-0.51%	1205.4	1213.0	7.6	0.63%	1186.0	1180.3	-5.6	-0.47%	1219.47	1185.96	-2.75%	1213.29	1180.33	-2.72%
		Utility Based (Coal)	5.71	1206.0	1211.2	5.2	0.43%	1199.8	1192.2	-7.5	-0.63%	1187.6	1185.7	-1.9	-0.16%	1205.99	1187.57	-1.53%	1211.22	1185.69	-2.11%
		Utility Based High	5.71	1206.0	1211.2	5.2	0.43%	1202.6	1199.7	-2.9	-0.25%	1186.7	1172.9	-13.9	-1.17%	1205.99	1186.74	-1.60%	1211.22	1172.87	-3.17%
	P(s)	Clear Sky w/Hg	12.19	12665.7	12641.7	-24.0	-0.19%	12529.8	12526.7	-3.1	-0.02%	12509.3	12514.7	5.4	0.04%	12665.74	12509.34	-1.23%	12641.75	12514.73	-1.00%
	3	Clear Sky wo/Hg	12.19	12593.1	12596.0	2.9	0.02%	12512.9	12559.0	46.2	0.37%	12437.1	12514.6	77.6	0.62%	12593.15	12437.06	-1.24%	12596.01	12514.62	-0.65%
		NAAQS	12.19	12611.5	12688.7	77.2	0.61%	12534.0	12538.7	4.7	0.04%	12470.7	12415.4	-55.3	-0.44%	12611.48	12470.72	-1.12%	12688.73	12415.39	-2.15%
		Utility Based (Coal)	12.19	12646.4	12624.2	-22.2	-0.18%	12568.1	12572.5	4.4	0.04%	12496.8	12487.9	-8.9	-0.07%	12646.36	12496.77	-1.18%	12624.15	12487.91	-1.08%
		Utility Based High	12.19	12646.4	12624.2	-22.2	-0.18%	12549.1	12494.9	-54.2	-0.43%	12454.3	12459.6	5.3	0.04%	12646.36	12454.30	-1.52%	12624.15	12459.57	-1.30%
	P(i)	Clear Sky w/Hg	11.80	17992.4	18022.4	29.9	0.17%	17149.2	17098.8	-50.4	-0.29%	16729.4	16716.0	-13.4	-0.08%	17992.44	16729.37	-7.02%	18022.36	16715.96	-7.25%
	4	Clear Sky wo/Hg	11.80	17805.9	17889.9	84.1	0.47%	17094.0	17073.6	-20.4	-0.12%	16452.2	16769.8	317.6	1.93%	17805.85	16452.22	-7.60%	17889.93	16769.84	-6.26%
		NAAQS	11.80	17835.0	17767.5	-67.6	-0.38%	17042.6	17231.0	188.4	1.11%	16265.4	16389.4	124.0	0.76%	17835.03	16265.42	-8.80%	17767.47	16389.45	-7.76%
		Utility Based (Coal)	11.80	17743.5	17795.4	51.9	0.29%	16917.7	17022.2	104.5	0.62%	16566.2	16163.5	-402.7	-2.43%	17743.53	16566.18	-6.64%	17795.42	16163.48	-9.17%
		Utility Based High	11.80	17743.5	17795.4	51.9	0.29%	17030.7	17022.6	-8.1	-0.05%	16002.3	16271.4	269.0	1.68%	17743.53	16002.33	-9.81%	17795.42	16271.37	-8.56%
	FD(i)	Clear Sky w/Hg	11.81	17735.4	17982.3	246.9	1.39%	17348.3	17384.2	35.9	0.21%	16787.3	16417.3	-370.1	-2.20%	17735.42	16787.34	-5.35%	17982.30	16417.25	-8.70%
	6	Clear Sky wo/Hg	11.81	17869.3	17709.5	-159.8	-0.89%	17259.4	17549.9	290.6	1.68%	16340.8	16867.5	526.7	3.22%	17869.26	16340.77	-8.54%	17709.48	16867.52	-4.75%
		NAAQS	11.81	17640.3	18216.7	576.4	3.27%	17322.2	17258.5	-63.7	-0.37%	16216.1	16663.7	447.7	2.76%	17640.31	16216.06	-8.07%	18216.71	16663.72	-8.53%
		Utility Based (Coal)	11.81	17870.0	17866.8	-3.2	-0.02%	17358.9	17136.6	-222.3	-1.28%	16953.8	16600.7	-353.1	-2.08%	17870.04	16953.84	-5.13%	17866.84	16600.71	-7.09%
		Utility Based High	11.81	17870.0	17866.8	-3.2	-0.02%	16718.7	17032.9	314.2	1.88%	16465.0	16192.0	-273.0	-1.66%	17870.04	16465.00	-7.86%	17866.84	16192.04	-9.37%
	S(s)	Clear Sky w/Hg	10.01	5455.5	5451.9	-3.6	-0.07%	5421.7	5419.8	-1.9	-0.04%	5265.8	5257.2	-8.7	-0.16%	5455.47	5265.82	-3.48%	5451.86	5257.16	-3.57%
	7	Clear Sky wo/Hg	10.01	5385.9	5420.9	35.0	0.65%	5391.5	5339.3	-52.2	-0.97%	5271.3	5263.2	-8.1	-0.15%	5385.86	5271.30	-2.13%	5420.89	5263.22	-2.91%
		NAAQS	10.01	5389.1	5469.2	80.1	1.49%	5319.0	5300.4	-18.6	-0.35%	5297.9	5255.4	-42.5	-0.80%	5389.10	5297.92	-1.69%	5469.18	5255.45	-3.91%
		Utility Based (Coal)	10.01	5411.1	5484.6	73.5	1.36%	5308.2	5424.1	115.9	2.18%	5269.7	5242.2	-27.5	-0.52%	5411.08	5269.72	-2.61%	5484.58	5242.18	-4.42%
		Utility Based High	10.01	5411.1	5484.6	73.5	1.36%	5345.8	5360.0	14.2	0.27%	5230.7	5286.1	55.5	1.06%	5411.08	5230.66	-3.31%	5484.58	5286.13	-3.63%
	S(i)	Clear Sky w/Hg	11.86	18852.2	18902.3	50.1	0.27%	18214.7	18151.7	-63.0	-0.35%	17682.6	17706.8	24.2	0.14%	18852.20	17682.63	-6.20%	18902.31	17706.84	-6.32%
	8	Clear Sky wo/Hg	11.86	18594.6	18822.9	228.3	1.23%	18160.9	18253.4	92.5	0.51%	17508.7	17966.3	457.6	2.61%	18594.63	17508.69	-5.84%	18822.89	17966.33	-4.55%
		NAAQS	11.86	18720.7	19260.1	539.4	2.88%	18188.2	18136.1	-52.1	-0.29%	17188.8	17377.4	188.5	1.10%	18720.71	17188.83	-8.18%	19260.11	17377.37	-9.78%
		Utility Based (Coal)	11.86	18875.2	18604.0	-271.2	-1.44%	17911.6	18074.2	162.6	0.91%	17465.1	17307.8	-157.3	-0.90%	18875.19	17465.06	-7.47%	18603.95	17307.78	-6.97%
		Utility Based High	11.86	18875.2	18604.0	-271.2	-1.44%	17921.4	17954.3	32.9	0.18%	17226.6	17351.2	124.6	0.72%	18875.19	17226.56	-8.73%	18603.95	17351.17	-6.73%
	SB(s)	Clear Sky w/Hg	8.34	117.7	118.7	1.0	0.81%	117.7	117.2	-0.5	-0.41%	112.2	110.4	-1.8	-1.65%	117.74	112.21	-4.70%	118.70	110.37	-7.02%
	14	Clear Sky wo/Hg	8.34	116.9	112.1	-4.8	-4.12%	113.2	114.4	1.2	1.07%	106.9	110.1	3.2	3.03%	116.86	106.86	-8.55%	112.05	110.09	-1.75%
		NAAQS	8.34	114.0	117.2	3.2	2.84%	111.9	110.5	-1.4	-1.24%	106.2	112.8	6.6	6.25%	114.01	106.16	-6.89%	117.25	112.80	-3.80%
		Utility Based (Coal)	8.34	120.4	114.8	-5.6	-4.69%	112.9	109.0	-3.9	-3.45%	109.6	109.3	-0.3	-0.28%	120.44	109.61	-9.00%	114.79	109.30	-4.75%
		Utility Based High	8.34	120.4	114.8	-5.6	-4.69%	107.6	108.5	0.9	0.82%	105.2	107.2	2.0	1.89%	120.44	105.23	-12.63%	114.79	107.22	-6.60%

TABLE 22
Newburgh Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Newburgh	ES(s)	Clear Sky w/Hg	8.38	2854.2	2869.6	15.3	0.54%	2844.5	2843.1	-1.4	-0.05%	2840.4	2831.8	-8.6	-0.30%	2854.21	2840.41	-0.48%	2869.55	2831.78	-1.32%
	1	Clear Sky wo/Hg	8.38	2831.4	2842.9	11.5	0.41%	2821.9	2849.8	27.9	0.99%	2774.4	2810.7	36.3	1.31%	2831.36	2774.41	-2.01%	2842.90	2810.68	-1.13%
		NAAQS	8.38	2839.4	2858.3	18.9	0.66%	2829.6	2834.5	4.9	0.17%	2767.0	2771.1	4.1	0.15%	2839.38	2767.02	-2.55%	2858.25	2771.13	-3.06%
		Utility Based (Coal)	8.38	2835.2	2827.3	-7.9	-0.28%	2824.5	2829.8	5.2	0.19%	2805.5	2797.3	-8.2	-0.29%	2835.24	2805.46	-1.05%	2827.29	2797.28	-1.06%
		Utility Based High	8.38	2835.2	2827.3	-7.9	-0.28%	2845.0	2840.9	-4.1	-0.14%	2794.8	2804.8	10.0	0.36%	2835.24	2794.80	-1.43%	2827.29	2804.82	-0.79%
	ES(f)	Clear Sky w/Hg	3.39	742.1	739.1	-3.0	-0.41%	737.2	737.8	0.6	0.08%	734.4	732.7	-1.8	-0.24%	742.08	734.42	-1.03%	739.07	732.66	-0.87%
	2	Clear Sky wo/Hg	3.39	737.8	739.4	1.6	0.21%	732.3	736.5	4.2	0.58%	731.0	728.2	-2.8	-0.38%	737.83	730.96	-0.93%	739.39	728.21	-1.51%
		NAAQS	3.39	739.8	739.9	0.1	0.01%	735.9	738.1	2.2	0.30%	730.5	729.8	-0.7	-0.10%	739.79	730.55	-1.25%	739.88	729.81	-1.36%
		Utility Based (Coal)	3.39	737.0	739.3	2.3	0.31%	733.5	732.3	-1.2	-0.17%	732.6	731.5	-1.0	-0.14%	736.98	732.55	-0.60%	739.25	731.52	-1.05%
		Utility Based High	3.39	737.0	739.3	2.3	0.31%	736.4	737.1	0.7	0.10%	733.0	727.9	-5.1	-0.69%	736.98	733.02	-0.54%	739.25	727.94	-1.53%
	P(s)	Clear Sky w/Hg	8.10	8164.4	8193.4	29.0	0.36%	8109.0	8115.1	6.0	0.07%	8085.8	8060.0	-25.8	-0.32%	8164.38	8085.84	-0.96%	8193.39	8060.03	-1.63%
	3	Clear Sky wo/Hg	8.10	8144.9	8139.1	-5.9	-0.07%	8066.7	8103.5	36.9	0.46%	8010.1	8040.4	30.3	0.38%	8144.91	8010.13	-1.65%	8139.06	8040.42	-1.21%
		NAAQS	8.10	8122.4	8203.2	80.8	0.99%	8077.2	8073.0	-4.2	-0.05%	8020.9	7995.7	-25.3	-0.31%	8122.44	8020.95	-1.25%	8203.25	7995.69	-2.53%
		Utility Based (Coal)	8.10	8165.0	8149.8	-15.2	-0.19%	8086.3	8111.7	25.3	0.31%	8068.0	8052.5	-15.5	-0.19%	8165.00	8068.04	-1.19%	8149.77	8052.51	-1.19%
		Utility Based High	8.10	8165.0	8149.8	-15.2	-0.19%	8090.5	8060.7	-29.8	-0.37%	8052.3	8040.1	-12.2	-0.15%	8165.00	8052.28	-1.38%	8149.77	8040.09	-1.35%
	P(l)	Clear Sky w/Hg	7.93	12669.1	12645.8	-23.3	-0.18%	12342.9	12303.1	-39.9	-0.32%	12078.5	12019.9	-58.6	-0.48%	12669.11	12078.47	-4.66%	12645.77	12019.91	-4.95%
	4	Clear Sky wo/Hg	7.93	12592.7	12596.1	3.4	0.03%	12162.6	12214.6	52.0	0.43%	11812.2	11948.3	136.1	1.15%	12592.66	11812.19	-6.20%	12596.07	11948.28	-5.14%
		NAAQS	7.93	12680.8	12651.1	-29.7	-0.23%	12111.3	12259.7	148.4	1.23%	11764.1	11919.4	155.3	1.32%	12680.82	11764.14	-7.23%	12651.12	11919.43	-5.78%
		Utility Based (Coal)	7.93	12635.6	12617.7	-17.9	-0.14%	12146.8	12298.9	152.1	1.25%	12046.9	11772.4	-274.5	-2.28%	12635.62	12046.91	-4.66%	12617.70	11772.42	-8.70%
		Utility Based High	7.93	12635.6	12617.7	-17.9	-0.14%	12285.5	12287.2	1.7	0.01%	11860.0	11991.6	131.6	1.11%	12635.62	11860.01	-6.14%	12617.70	11991.57	-4.96%
	FD(l)	Clear Sky w/Hg	7.95	12572.0	12768.8	196.7	1.56%	12246.9	12304.4	57.5	0.47%	12004.6	11947.8	-56.8	-0.47%	12572.03	12004.62	-4.51%	12768.78	11947.79	-6.43%
	6	Clear Sky wo/Hg	7.95	12585.0	12576.4	-8.7	-0.07%	12243.6	12291.6	48.0	0.39%	11821.0	12042.2	221.2	1.87%	12585.02	11821.04	-6.07%	12576.36	12042.20	-4.25%
		NAAQS	7.95	12536.4	12733.3	196.8	1.57%	12388.6	12245.1	-143.5	-1.16%	11793.7	11929.0	135.3	1.15%	12536.43	11793.67	-5.92%	12733.25	11928.97	-6.33%
		Utility Based (Coal)	7.95	12755.5	12739.9	-15.5	-0.12%	12282.2	12205.6	-76.6	-0.62%	12279.9	12049.0	-230.9	-1.88%	12755.48	12279.92	-3.73%	12739.93	12049.05	-5.42%
		Utility Based High	7.95	12755.5	12739.9	-15.5	-0.12%	12201.1	12324.1	123.0	1.01%	12188.5	11925.7	-262.9	-2.16%	12755.48	12188.53	-4.44%	12739.93	11925.65	-6.39%
	S(s)	Clear Sky w/Hg	7.93	4367.7	4365.8	-1.9	-0.04%	4369.7	4375.4	5.6	0.13%	4247.2	4240.5	-6.7	-0.16%	4367.72	4247.21	-2.76%	4365.83	4240.50	-2.87%
	7	Clear Sky wo/Hg	7.93	4289.7	4327.0	37.4	0.87%	4281.3	4256.5	-24.8	-0.58%	4230.2	4235.9	5.7	0.13%	4289.65	4230.19	-1.39%	4327.02	4235.90	-2.11%
		NAAQS	7.93	4330.2	4382.3	52.1	1.20%	4288.5	4276.5	-12.0	-0.28%	4252.1	4247.5	-4.7	-0.11%	4330.21	4252.15	-1.80%	4382.28	4247.48	-3.08%
		Utility Based (Coal)	7.93	4344.0	4379.1	35.1	0.81%	4301.3	4339.1	37.8	0.88%	4249.8	4246.4	-3.5	-0.08%	4343.98	4249.83	-2.17%	4379.11	4246.37	-3.03%
		Utility Based High	7.93	4344.0	4379.1	35.1	0.81%	4309.1	4293.1	-16.0	-0.37%	4245.8	4274.5	28.8	0.68%	4343.98	4245.76	-2.26%	4379.11	4274.55	-2.39%
	S(l)	Clear Sky w/Hg	7.91	12997.1	12993.9	-3.2	-0.02%	12736.6	12698.6	-38.0	-0.30%	12412.1	12490.6	78.5	0.63%	12997.10	12412.14	-4.50%	12993.87	12490.63	-3.87%
	8	Clear Sky wo/Hg	7.91	12863.6	12952.1	88.5	0.69%	12676.2	12597.8	-78.4	-0.62%	12271.4	12404.7	133.3	1.09%	12863.56	12271.41	-4.60%	12952.07	12404.72	-4.23%
		NAAQS	7.91	13034.0	13242.1	208.1	1.60%	12695.7	12609.4	-86.2	-0.68%	12141.1	12310.2	169.1	1.39%	13034.03	12141.13	-6.85%	13242.12	12310.19	-7.04%
		Utility Based (Coal)	7.91	13050.7	13089.5	38.8	0.30%	12542.1	12603.2	61.1	0.49%	12296.4	12287.1	-9.3	-0.08%	13050.68	12296.42	-5.78%	13089.47	12287.07	-6.13%
		Utility Based High	7.91	13050.7	13089.5	38.8	0.30%	12669.5	12565.8	-103.7	-0.82%	12422.6	12424.3	1.8	0.01%	13050.68	12422.55	-4.81%	13089.47	12424.32	-5.08%
	SB(s)	Clear Sky w/Hg	3.68	36.0	36.7	0.6	1.78%	36.6	36.5	-0.1	-0.23%	34.4	33.6	-0.9	-2.54%	36.03	34.44	-4.40%	36.67	33.56	-8.46%
	14	Clear Sky wo/Hg	3.68	37.0	35.1	-1.9	-5.23%	34.6	35.7	1.1	3.11%	33.4	33.8	0.3	0.97%	37.01	33.44	-9.65%	35.08	33.77	-3.73%
		NAAQS	3.68	36.0	36.0	-0.1	-0.17%	35.3	33.9	-1.4	-3.98%	31.7	32.9	1.2	3.87%	36.01	31.70	-11.99%	35.95	32.92	-8.43%
		Utility Based (Coal)	3.68	37.9	36.6	-1.3	-3.47%	34.6	33.1	-1.5	-4.22%	34.0	33.7	-0.3	-0.95%	37.95	34.00	-10.40%	36.63	33.67	-8.09%
		Utility Based High	3.68	37.9	36.6	-1.3	-3.47%	33.7	33.6	-0.1	-0.28%	33.3	33.3	0.1	0.16%	37.95	33.28	-12.29%	36.63	33.33	-9.00%

TABLE 23
J T Myers Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
JTMyers	ES(s)	Clear Sky w/Hg	11.28	3963.3	3970.8	7.5	0.19%	3907.4	3919.2	11.8	0.30%	3892.1	3884.3	-7.8	-0.20%	3963.30	3892.13	-1.80%	3970.81	3884.30	-2.18%
	1	Clear Sky wo/Hg	11.28	3924.1	3911.8	-12.3	-0.31%	3894.2	3905.1	10.9	0.28%	3828.4	3853.6	25.1	0.66%	3924.14	3828.41	-2.44%	3911.85	3853.55	-1.49%
		NAAQS	11.28	3940.9	3973.4	32.4	0.82%	3916.2	3909.7	-6.5	-0.17%	3801.8	3795.5	-6.3	-0.17%	3940.94	3801.79	-3.53%	3973.37	3795.45	-4.48%
		Utility Based (Coal)	11.28	3920.0	3910.0	-10.0	-0.25%	3901.0	3917.2	16.2	0.42%	3835.7	3819.2	-16.5	-0.43%	3919.96	3835.73	-2.15%	3910.00	3819.19	-2.32%
		Utility Based High	11.28	3920.0	3910.0	-10.0	-0.25%	3914.4	3936.3	21.9	0.56%	3846.1	3838.7	-7.3	-0.19%	3919.96	3846.07	-1.89%	3910.00	3838.74	-1.82%
	ES(f)	Clear Sky w/Hg	6.26	1370.7	1367.7	-3.0	-0.22%	1360.4	1360.8	0.3	0.02%	1351.1	1350.3	-0.7	-0.05%	1370.67	1351.06	-1.43%	1367.68	1350.33	-1.27%
	2	Clear Sky wo/Hg	6.26	1361.9	1368.1	6.2	0.46%	1350.9	1356.8	5.9	0.44%	1352.1	1342.5	-9.6	-0.71%	1361.91	1352.08	-0.72%	1368.11	1342.46	-1.87%
		NAAQS	6.26	1367.0	1365.9	-1.0	-0.08%	1357.2	1361.8	4.6	0.34%	1348.7	1347.6	-1.1	-0.08%	1366.99	1348.67	-1.34%	1365.95	1347.55	-1.35%
		Utility Based (Coal)	6.26	1359.9	1363.6	3.7	0.27%	1354.8	1352.7	-2.1	-0.16%	1349.3	1346.2	-3.1	-0.23%	1359.90	1349.29	-0.78%	1363.56	1346.21	-1.27%
		Utility Based High	6.26	1359.9	1363.6	3.7	0.27%	1357.6	1363.0	5.3	0.39%	1352.5	1341.3	-11.2	-0.83%	1359.90	1352.49	-0.54%	1363.56	1341.27	-1.63%
	P(s)	Clear Sky w/Hg	9.31	9531.5	9537.6	6.2	0.06%	9460.6	9464.5	3.9	0.04%	9405.3	9399.2	-6.1	-0.06%	9531.46	9405.28	-1.32%	9537.63	9399.18	-1.45%
	3	Clear Sky wo/Hg	9.31	9487.7	9510.1	22.4	0.24%	9452.9	9446.0	-6.9	-0.07%	9313.0	9365.8	52.9	0.57%	9487.70	9312.96	-1.84%	9510.12	9365.82	-1.52%
		NAAQS	9.31	9490.2	9544.0	53.7	0.57%	9420.8	9422.0	1.2	0.01%	9338.9	9319.4	-19.5	-0.21%	9490.23	9338.89	-1.59%	9543.96	9319.38	-2.35%
		Utility Based (Coal)	9.31	9506.9	9515.5	8.5	0.09%	9448.5	9432.3	-16.2	-0.17%	9386.0	9348.2	-37.9	-0.40%	9506.94	9386.04	-1.27%	9515.49	9348.19	-1.76%
		Utility Based High	9.31	9506.9	9515.5	8.5	0.09%	9433.1	9399.5	-33.6	-0.36%	9383.6	9366.7	-16.9	-0.18%	9506.94	9383.58	-1.30%	9515.49	9366.71	-1.56%
	P(i)	Clear Sky w/Hg	9.69	15898.1	15814.4	-83.7	-0.53%	15554.2	15539.3	-14.9	-0.10%	15134.6	15176.8	42.2	0.28%	15898.12	15134.63	-4.80%	15814.39	15176.80	-4.03%
	4	Clear Sky wo/Hg	9.69	15779.3	15797.5	18.2	0.12%	15206.7	15347.1	140.4	0.92%	14932.1	15027.9	95.8	0.64%	15779.33	14932.05	-5.37%	15797.55	15027.90	-4.87%
		NAAQS	9.69	15803.3	15732.7	-70.6	-0.45%	15225.6	15401.6	176.0	1.16%	14840.7	14879.4	38.7	0.26%	15803.30	14840.68	-6.09%	15732.69	14879.39	-5.42%
		Utility Based (Coal)	9.69	15753.6	15759.4	5.8	0.04%	15169.6	15378.1	208.5	1.37%	15008.6	14705.3	-303.4	-2.02%	15753.63	15008.64	-4.73%	15759.41	14705.26	-6.69%
		Utility Based High	9.69	15753.6	15759.4	5.8	0.04%	15415.7	15382.5	-33.2	-0.22%	14858.8	14955.5	96.7	0.65%	15753.63	14858.80	-5.65%	15759.41	14955.50	-5.10%
	FD(i)	Clear Sky w/Hg	9.67	15472.8	15788.4	315.6	2.04%	15319.2	15336.7	17.5	0.11%	14946.9	14811.5	-135.4	-0.91%	15472.79	14946.86	-3.40%	15788.37	14811.49	-6.19%
	6	Clear Sky wo/Hg	9.67	15519.9	15662.4	142.5	0.92%	15303.1	15147.2	-155.9	-1.02%	14671.1	15096.3	425.2	2.90%	15519.85	14671.09	-5.47%	15662.36	15096.31	-3.61%
		NAAQS	9.67	15727.6	15710.0	-17.6	-0.11%	15359.9	15312.5	-47.4	-0.31%	14840.7	14867.4	26.7	0.18%	15727.62	14840.72	-5.64%	15710.02	14867.37	-5.36%
		Utility Based (Coal)	9.67	15833.8	15761.6	-72.2	-0.46%	15353.7	15181.0	-172.7	-1.12%	15192.4	14905.5	-286.8	-1.89%	15833.80	15192.39	-4.05%	15761.61	14905.55	-5.43%
		Utility Based High	9.67	15833.8	15761.6	-72.2	-0.46%	15169.1	15309.6	140.6	0.93%	14960.4	14674.1	-286.3	-1.91%	15833.80	14960.40	-5.57%	15761.61	14674.07	-6.90%
	S(s)	Clear Sky w/Hg	9.19	5229.0	5221.7	-7.2	-0.14%	5220.9	5226.7	5.8	0.11%	5145.6	5180.6	35.0	0.68%	5228.95	5145.56	-1.59%	5221.73	5180.56	-0.79%
	7	Clear Sky wo/Hg	9.19	5188.3	5228.4	40.1	0.77%	5176.0	5187.7	11.7	0.23%	5094.9	5122.2	27.3	0.54%	5188.33	5094.93	-1.80%	5228.43	5122.24	-2.03%
		NAAQS	9.19	5201.6	5264.4	62.7	1.21%	5142.1	5138.2	-3.9	-0.08%	5149.3	5112.3	-37.0	-0.72%	5201.62	5149.32	-1.01%	5264.35	5112.33	-2.89%
		Utility Based (Coal)	9.19	5216.4	5251.5	35.1	0.67%	5152.6	5206.2	53.6	1.04%	5115.0	5122.6	7.6	0.15%	5216.41	5114.98	-1.94%	5251.49	5122.58	-2.45%
		Utility Based High	9.19	5216.4	5251.5	35.1	0.67%	5141.9	5187.9	46.0	0.89%	5138.6	5164.8	26.2	0.51%	5216.41	5138.64	-1.49%	5251.49	5164.82	-1.65%
	S(i)	Clear Sky w/Hg	9.76	16365.7	16417.5	51.7	0.32%	16126.2	16110.5	-15.7	-0.10%	15673.2	15756.8	83.6	0.53%	16365.73	15673.16	-4.23%	16417.48	15756.75	-4.02%
	8	Clear Sky wo/Hg	9.76	16254.6	16346.5	91.9	0.57%	16023.6	15949.1	-74.5	-0.46%	15502.8	15745.3	242.5	1.56%	16254.57	15502.82	-4.62%	16346.52	15745.32	-3.68%
		NAAQS	9.76	16398.2	16604.0	205.8	1.25%	15946.9	15932.0	-14.9	-0.09%	15351.1	15553.3	202.3	1.32%	16398.19	15351.06	-6.39%	16603.98	15553.31	-6.33%
		Utility Based (Coal)	9.76	16353.1	16378.2	25.1	0.15%	15867.8	15844.0	-23.8	-0.15%	15559.0	15489.5	-69.5	-0.45%	16353.07	15559.04	-4.86%	16378.17	15489.54	-5.43%
		Utility Based High	9.76	16353.1	16378.2	25.1	0.15%	15840.0	15853.5	13.5	0.08%	15608.4	15609.8	1.4	0.01%	16353.07	15608.39	-4.55%	16378.17	15609.76	-4.69%
	SB(s)	Clear Sky w/Hg	4.59	45.2	48.1	3.0	6.53%	47.6	47.9	0.3	0.56%	44.1	43.8	-0.3	-0.66%	45.18	44.08	-2.44%	48.13	43.79	-9.02%
	14	Clear Sky wo/Hg	4.59	46.4	44.7	-1.7	-3.66%	45.7	48.3	2.6	5.69%	42.0	42.6	0.6	1.52%	46.40	42.01	-9.47%	44.70	42.65	-4.59%
		NAAQS	4.59	47.5	46.9	-0.6	-1.24%	45.4	44.1	-1.3	-2.77%	40.7	44.5	3.8	9.27%	47.53	40.72	-14.33%	46.94	44.49	-5.22%
		Utility Based (Coal)	4.59	48.2	47.0	-1.2	-2.58%	46.4	43.1	-3.4	-7.23%	43.9	43.6	-0.4	-0.80%	48.20	43.91	-8.91%	46.96	43.55	-7.24%
		Utility Based High	4.59	48.2	47.0	-1.2	-2.58%	43.3	43.7	0.4	0.86%	43.8	43.2	-0.5	-1.24%	48.20	43.75	-9.22%	46.96	43.21	-7.98%

TABLE 24
Smithland Pool
NAVPAT Data

Pool	Fish Species/ Life Stage	Traffic Forecast Scenario	% of Total River HSI Units	2010 Without Project HSI Units	2010 With Project HSI Units	2010 Delta	2010 % Delta	2040 Without Project HSI Units	2040 With Project HSI Units	2040 Delta	2040 % Delta	2070 Without Project HSI Units	2070 With Project HSI Units	2070 Delta	2070 % Delta	2010-2070 Without Project 2010	2010-2070 Without Project 2070	2010-2070 % Delta	2010-2070 With Project 2010	2010-2070 With Project 2070	2010-2070 % Delta
Smithland	ES(a)	Clear Sky w/Hg	4.79	1826.217	1822.304	-3.9	-0.21%	1805.714	1806.248	0.5	0.03%	1814.638	1804.251	-10.4	-0.57%	1826.22	1814.64	-0.63%	1822.30	1804.25	-0.99%
		Clear Sky w/oHg	4.79	1815.755	1813.467	-2.3	-0.13%	1799.958	1798.177	-3.8	-0.21%	1784.449	1791.653	7.2	0.40%	1815.76	1784.45	-1.72%	1813.47	1791.65	-1.20%
		NAAQS	4.79	1814.576	1824.204	9.6	0.53%	1802.461	1800.166	-2.3	-0.13%	1787.847	1783.847	-4.0	-0.22%	1814.58	1787.85	-1.47%	1824.20	1783.85	-2.21%
		Utility Based (Coal)	4.79	1814.106	1809.537	-4.6	-0.25%	1798.562	1798.942	1.4	0.08%	1792.99	1786.177	-6.8	-0.38%	1814.11	1792.99	-1.16%	1809.54	1786.18	-1.29%
		Utility Based High	4.79	1814.106	1809.537	-4.6	-0.25%	1796.426	1805.946	6.4	0.36%	1784.757	1786.734	2.0	0.11%	1814.11	1784.76	-1.62%	1809.54	1786.73	-1.26%
	ES(f)	Clear Sky w/Hg	2.15	466.3759	464.621	-1.8	-0.38%	462.0236	462.5175	0.5	0.11%	458.5298	458.8051	0.3	0.06%	466.38	458.53	-1.68%	464.62	458.81	-1.25%
	2	Clear Sky w/oHg	2.15	463.3846	463.9683	0.6	0.13%	458.9324	458.9129	0.0	0.00%	457.7385	454.8922	-2.8	-0.62%	463.38	457.74	-1.22%	463.97	454.89	-1.96%
		NAAQS	2.15	464.9538	463.7005	-1.3	-0.27%	460.2909	461.458	1.2	0.25%	456.537	459.1613	2.6	0.57%	464.96	456.54	-1.81%	463.70	459.16	-0.98%
		Utility Based (Coal)	2.15	463.0997	464.828	1.7	0.37%	456.573	458.3891	1.8	0.40%	456.1021	454.611	-1.5	-0.33%	463.10	456.10	-1.51%	464.83	454.61	-2.22%
		Utility Based High	2.15	463.0997	464.828	1.7	0.37%	459.9038	460.1633	0.3	0.06%	453.4504	451.1088	-2.3	-0.52%	463.10	453.45	-2.08%	464.83	451.11	-2.95%
	PI(s)	Clear Sky w/Hg	4.11	4259.064	4266.117	7.1	0.17%	4230.027	4234.176	4.1	0.10%	4230.373	4227.63	-2.7	-0.06%	4259.06	4230.37	-0.67%	4266.12	4227.63	-0.90%
	3	Clear Sky w/oHg	4.11	4243.923	4256.393	12.5	0.29%	4233.926	4234.72	0.8	0.02%	4198.947	4207.937	9.0	0.21%	4243.92	4198.95	-1.06%	4256.39	4207.94	-1.14%
		NAAQS	4.11	4249.292	4272.675	23.4	0.55%	4222.01	4228.888	6.9	0.16%	4202.053	4202.07	0.0	0.00%	4249.29	4202.05	-1.11%	4272.68	4202.07	-1.66%
		Utility Based (Coal)	4.11	4262.116	4262.821	0.7	0.02%	4234.94	4230.672	-4.1	-0.10%	4221.022	4213.719	-7.3	-0.17%	4262.12	4221.02	-0.96%	4262.82	4213.72	-1.15%
		Utility Based High	4.11	4262.116	4262.821	0.7	0.02%	4218.283	4220.116	1.8	0.04%	4214.962	4207.947	-7.0	-0.17%	4262.12	4214.96	-1.11%	4262.82	4207.95	-1.29%
	PI(j)	Clear Sky w/Hg	4.33	7075.217	7024.262	-50.9	-0.72%	6897.942	6907.108	9.2	0.13%	6721.318	6728.247	4.9	0.07%	7075.22	6721.32	-5.00%	7024.29	6728.25	-4.22%
	4	Clear Sky w/oHg	4.33	7037.58	7042.299	4.7	0.07%	6759.43	6788.013	28.6	0.42%	6589.741	6588.184	-1.6	-0.02%	7037.58	6589.74	-6.36%	7042.29	6588.18	-6.40%
		NAAQS	4.33	7049.443	6974.981	-74.5	-1.06%	6721.196	6801.228	80.0	1.19%	6518.488	6559.542	41.1	0.63%	7049.44	6518.49	-7.52%	6974.98	6559.54	-6.35%
		Utility Based (Coal)	4.33	7008.953	6999.777	-9.2	-0.13%	6873.474	6781.168	87.7	1.31%	6556.891	6491.521	-67.4	-1.03%	7008.95	6556.89	-6.42%	6999.78	6491.52	-7.29%
		Utility Based High	4.33	7006.953	6999.777	-9.2	-0.13%	6712.07	6681.105	-31.0	-0.46%	6423.581	6452.89	29.1	0.45%	7008.95	6423.58	-8.35%	6999.78	6452.89	-7.87%
	FD(a)	Clear Sky w/Hg		3826.408	3825.099	-1.3	-0.03%	3825.141	3823.191	0.1	0.00%	3822.101	3821.996	-0.2	-0.01%	3826.41	3822.10	-0.11%	3825.10	3821.99	-0.08%
	5	Clear Sky w/oHg		3826.281	3826.845	0.4	0.01%	3821.939	3823.075	1.1	0.03%	3821.169	3821.171	0.0	0.00%	3826.28	3821.17	-0.13%	3826.85	3821.17	-0.14%
		NAAQS		3824.979	3824.67	-0.3	-0.01%	3822.781	3823.131	0.4	0.01%	3820.853	3820.184	-0.7	-0.02%	3824.98	3820.85	-0.11%	3824.67	3820.18	-0.12%
		Utility Based (Coal)		3825.38	3824.848	-0.5	-0.01%	3822.988	3824.049	1.4	0.04%	3822.448	3821.328	-1.1	-0.03%	3825.38	3822.45	-0.08%	3824.85	3821.33	-0.09%
		Utility Based High		3825.38	3824.848	-0.5	-0.01%	3823.309	3823.452	0.2	0.00%	3821.302	3821.44	0.1	0.00%	3825.38	3821.30	-0.11%	3824.85	3821.44	-0.09%
	FD(i)	Clear Sky w/Hg	4.34	6907.001	7039.453	132.5	1.92%	6866.102	6881.832	15.7	0.23%	6676.69	6822.976	-53.9	-0.81%	6907.00	6676.69	-3.33%	7039.45	6822.98	-3.05%
	6	Clear Sky w/oHg	4.34	6893.838	7036.966	43.3	0.62%	6901.078	6740.473	-160.6	-2.33%	6515.724	6646.376	130.7	2.05%	6893.84	6515.72	-5.48%	7036.97	6646.38	-5.52%
		NAAQS	4.34	7035.86	7036.692	1.0	0.01%	6834.2	6823.591	-10.6	-0.16%	6698.4	6548.385	-120.0	-1.80%	7035.86	6698.40	-4.80%	7036.69	6548.39	-6.94%
		Utility Based (Coal)	4.34	7105.234	7050.931	-54.3	-0.76%	6788.9	6765.756	-23.1	-0.34%	6699.358	6568.155	-101.2	-1.52%	7105.23	6699.36	-5.73%	7050.93	6568.15	-6.86%
		Utility Based High	4.34	7105.234	7050.931	-54.3	-0.76%	6699.332	6877.736	68.4	1.03%	6494.953	6412.819	-51.6	-0.80%	7105.23	6494.68	-8.60%	7050.93	6412.82	-9.05%
	SI(s)	Clear Sky w/Hg	3.03	1738.231	1743.393	4.7	0.27%	1730.797	1734.513	3.8	0.22%	1699.65	1706.117	6.5	0.38%	1738.23	1699.65	-2.28%	1743.39	1706.12	-2.14%
	7	Clear Sky w/oHg	3.03	1722.232	1730.519	8.3	0.48%	1704.915	1706.937	2.0	0.12%	1691.745	1696.572	4.8	0.29%	1722.23	1691.75	-1.77%	1730.52	1696.57	-1.96%
		NAAQS	3.03	1729.096	1740.651	11.6	0.67%	1706.223	1697.484	-8.7	-0.51%	1704.414	1691.013	-13.4	-0.79%	1729.10	1704.41	-1.45%	1740.65	1691.01	-2.85%
		Utility Based (Coal)	3.03	1737.714	1738.946	1.2	0.07%	1711.812	1718.082	7.3	0.42%	1696.743	1701.052	2.3	0.14%	1737.71	1698.74	-2.24%	1738.95	1701.05	-2.18%
		Utility Based High	3.03	1737.714	1738.946	1.2	0.07%	1703.759	1710.418	6.7	0.39%	1692.83	1697.663	4.9	0.29%	1737.71	1692.83	-2.58%	1738.95	1697.66	-2.37%
	SI(j)	Clear Sky w/Hg	4.31	7106.838	7149.193	79.4	1.12%	7010.73	7033.837	23.2	0.33%	6846.981	6876.845	30.9	0.45%	7106.83	6845.98	-3.68%	7149.19	6876.84	-3.82%
	8	Clear Sky w/oHg	4.31	7104.787	7140.935	36.1	0.51%	6943.976	6924.15	-19.8	-0.29%	6696.058	6785.461	89.4	1.34%	7104.79	6696.06	-5.76%	7140.93	6785.46	-4.96%
		NAAQS	4.31	7152.077	7222.869	70.8	0.99%	6895.584	6920.719	25.1	0.36%	6661.862	6749.551	87.7	1.32%	7152.08	6661.86	-6.88%	7222.87	6749.55	-6.55%
		Utility Based (Coal)	4.31	7147.951	7182.247	34.3	0.48%	6858.808	6829.088	-29.7	-0.43%	6712.326	6714.358	2.0	0.03%	7147.95	6712.33	-6.09%	7182.25	6714.36	-6.51%
		Utility Based High	4.31	7147.951	7182.247	34.3	0.48%	6786.255	6727.684	-58.6	-0.72%	6650.807	6621.789	-29.0	-0.44%	7147.95	6650.81	-6.96%	7182.25	6621.79	-7.80%
	CO(y)	Clear Sky w/Hg		252.6599	252.6499	0.0	0.00%	252.6155	252.6196	0.0	0.00%	252.665	252.6607	0.0	0.00%	252.66	252.67	0.00%	252.65	252.66	0.00%
	9	Clear Sky w/oHg		252.6797	252.6429	0.0	-0.01%	252.632	252.6172	0.0	-0.01%	252.6594	252.6518	0.0	0.00%	252.68	252.66	-0.01%	252.64	252.65	0.00%
		NAAQS		252.6439	252.6249	0.0	-0.01%	252.6732	252.674	0.0	0.00%	252.6657	252.6475	0.0	-0.01%	252.64	252.67	0.01%	252.62	252.65	0.01%
		Utility Based (Coal)		252.6513	252.6638	0.0	0.00%	252.7104	252.6694	0.0	-0.02%	252.6787	252.6761	0.0	0.00%	252.65	252.68	0.01%	252.66	252.68	0.00%
		Utility Based High		252.6513	252.6638	0.0	0.00%	252.6268	252.6445	0.0	0.01%	252.7019	252.6827	0.0	-0.01%	252.65	252.70	0.02%	252.66	252.68	0.01%
	BC(s)	Clear Sky w/Hg		80.09589	80.08038	0.0	0.02%	79.80183	79.72027	-0.1	-0.10%	79.8095	79.89952	0.1	0.12%	80.07	79.81	-0.32%	80.08	79.90	-0.23%
	10	Clear Sky w/oHg		79.85235	79.94496	-0.2	-0.29%	80.20712	79.85856	-0.3	-0.43%	79.76649	79.98541	0.2	0.29%	79.85	79.77	-0.11%	79.94	80.00	0.44%
		NAAQS		80.00369	80.01593	0.0	-0.02%	80.03003	80.23842	0.2	0.24%	79.82193	80.16659	0.3	0.43%	80.03	79.82	-0.26%	80.02	80.17	0.19%
		Utility Based (Coal)		79.739	80.22461	0.5	0.61%	79.73582	80.07919	0.3	0.43%	80.0537	79.87132	-0.2	-0.23%	79.74	80.05	0.32%	80.22	79.87	-0.44%
		Utility Based High		79.739	80.22461	0.5	0.61%	80.12109	79.76339	-0.4	-0.46%	80.11855	79.83674	-0.3	-0.35%	79.74	80.12	0.47%	80.22	79.84	-0.48%
	BC(f)	Clear Sky w/Hg		81.92156	81.93554	0.0	0.02%	81.68215	81.68133	0.0	-0.03%	81.86633	81.8753	0.0	0.01%	81.92	81.87	-0.07%	81.94	81.88	-0.07%
	11	Clear Sky w/oHg		81.89116	81.82753	-0.1	-0.08%	81.94239	81.87691	-0.1	-0.08%	81.96412	81.89731	0.0	0.04%	81.89	81.96	-0.03%	81.83	81.90	0.09%
		NAAQS		81.9157	81.9044	0.0	0.01%	81.91921	81.943	0.0	0.03%	81.88451	81.93369	0.0	0.06%	81.92	81.88	-0.04%	81.90	81.93	0.04%
		Utility Based (Coal)		81.8345	81.9527	0.1	0.14%	81.86062	81.90445	0.0	0.05%	81.92342	81.8877	0.0	-0.04%	81.83	81.92	0.11%	81.95	81.89	-0.06%
		Utility Based High		81.8345	81.9527	0.1	0.14%	81.91133	81.86216	0.0	-0.06%	81.90539	81.86723	0.0	-0.05%	81.83	81.91	0.09%	81.95	81.87	-0.10%
	BC(j)	Clear Sky w/Hg		1242.827	1242.798	0.0	0.00%	1242.685	1242.663	0.0	0.00%	1242.553	1242.49	-0.1	-0.01%	1242.83	1242.55	-0.02%	1242.80	1242.49	-0.02%
	12	Clear Sky w/oHg		1242.782	1242.71	-0.1	0.00%	1242.598	1242.594	0.0	0.00%	1242.431	1242.585	0.2	0.01%	1242.78	1242.43	-0.03%	1242.71	1242.59	-0.01%
		NAAQS		1242.754	1242.793	0.0	0.00%	1242.884	1242.681	0.0	0.00%	1242.43	1242.554	0.1	0.01%	1242.75	1242.43	-0.03%	1242.79	1242.55	-0.02%
		Utility Based (Coal)		1242.847	1242.689	-0.2	-0.01%	1242.628	1242.587	0.0	0.00%	1242.561	1242.617	0.0	0.00%	1242.85	1242.58	-0.02%	1242.67	1242.62	0.00%
		Utility Based High		1242.847	1242.689	-0.2	-0.01%	1242.585	1242.621	0.0	0.00%	1242.558	1242.427	-0.1	-0.01%	1242.85	1242.58	-0.02%	1242.67	1242.43	-0.02%
	BC(e)	Clear Sky w/Hg		1860.825	1860.872	0.0	0.00%	1860.681	1860.602	-0.1	0.00%	1860.358	1860.368	0.0	0.00%	1860.83	1860.36	-0.03%	1860.87	1860.37	-0.03%
	13	Clear Sky w/oHg		1860.832	1860.758	-0.1	-0.01%	1860.536	1860.416	-0.1	-0.01%	1860.205	1860.265	0.1	0.00%	1860.83	1860.21	-0.05%	1860.71	1860.28	-0.02%
		NAAQS		1860.96	1860.922	0.1	0.00%	1860.509	1860.527	0.0	0.00%	1860.25	1860.329	0.1	0.00%	1860.86	1860.25	-0.03%	1860.92	1860.33	-0.03%
		Utility Based (Coal)		1860.764	1860.765	0.0	0.00%	1860.507	1860.546	0.0	0.00%	1860.418	1860.459	0.0	0.00%	1860.76	1860.42	-0.02%	1860.80	1860.46	-0.02%
		Utility Based High		1860.764	1860.765	0.0	0.00%	1860.536	1860.556	0.0	0.00%	1860.249	1860.319	0.1	0.00%	1860.76	1860.25	-0.03%	1860.80	1860.32	-0.03%
	SB(s)	Clear Sky w/Hg	1.75	23.83072	23.99976	1.4	0.69%	24.31292	24.56591	-0.2	-1.03%	24.29508	23.88075	-0.4	-1.71%	23.84	24.30	2.00%	25.07	23.88	-4.76%
	14	Clear Sky w/oHg	1.75	24.25296	23.70897	-0.5	-2.24%	24.0194	24.05708	0.0	0.20%	22.87066	23.14224	0.3	1.19%	24.25	22.87	-5.70%	23.71	23.14	-2.39%
		NAAQS	1.75	24.11122	24.59181	0.5	1.99%	23.62628	23.4746	-0.2	-0.64%	23.12634	23.22481	0.1	0.43%	24.11	23.13	-4.05%	24.59	23.22	-5.57%
		Utility Based (Coal)	1.75	25.16858	24.75636	-0.4	-1.64%	23.58706	23.38085	-0.2	-0.88%	23.67835	23.08099	-0.6	-2.52%	25.17	23.68	-5.91%	24.76	23.08	-6.77%
		Utility Based High	1.75	25.16858	24.75636	-0.4	-1.64%	22.72659	22.56817	-0.1	-0.60%	22.61423	22.51721	-0.1	-0.43%	25.17	22.61	-10.15%	24.76	22.52	-9.06%
	SB(j)	Clear Sky w/Hg		590.9089	590.7903	0.0	0.00%	590.7173	590.702	0.0	0.00%	590.7939	590.7586	0.0	0.00%	590.91	590.80	0.00%	590.79	590.77	0.00%
	15	Clear Sky w/oHg		590.7675	590.7571	0.0	0.00%	590.7945	590.8378	0.0	0.01%	590.7524	590.7528	0.0	0.00%	590.77	590.75	0.00%	590.78	590.75	0.00%
		NAAQS		590.7597	590.7513	0.0	0.00%	590.7476	590.7616	0.0	0.00%	590.8146	590.8173	0.0	0.00%	590.76	590.81	0.01%	590.75	590.82	0.01%
		Utility Based (Coal)		590.8099	590.8189	0.0	0.00%	590.737	590.7171	0.0	0.00%	590.7569	590.7681	0.0	0.00%	590.80	590.76	-0.01%	590.82	590.77	-0.01%
		Utility Based High		590.7805	590.7411	0.0	-0.01%	590.8146	590.8173	0.0	0.00%	590.7225	590.7084	0.0	0.00%	590.78	590.72	-0.01%	590.74	590.71	-0.01%

TABLE 25
Lock Dam 52 Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
L&D 52	ES(s)	Clear Sky w/Hg	0.96	342.7	340.8	-1.8	-0.54%	338.7	339.3	0.5	0.15%	343.5	341.5	-2.0	-0.59%	342.67	343.55	0.25%	340.83	341.53	0.21%
	1	Clear Sky wo/Hg	0.96	340.6	339.5	-1.1	-0.33%	338.4	340.7	2.3	0.67%	336.7	338.5	1.9	0.56%	340.62	336.66	-1.16%	339.50	338.55	-0.28%
		NAAQS	0.96	340.2	341.7	1.5	0.43%	339.4	337.4	-2.0	-0.59%	336.6	335.2	-1.4	-0.41%	340.21	336.60	-1.06%	341.67	335.21	-1.89%
		Utility Based (Coal)	0.96	340.9	341.7	0.8	0.24%	339.7	338.3	-1.3	-0.39%	339.2	338.9	-0.3	-0.09%	340.91	339.23	-0.49%	341.74	338.91	-0.83%
		Utility Based High	0.96	340.9	341.7	0.8	0.24%	340.3	339.9	-0.4	-0.11%	336.7	339.4	2.7	0.80%	340.91	336.66	-1.25%	341.74	339.35	-0.70%
	ES(f)	Clear Sky w/Hg	0.67	151.1	151.0	-0.1	-0.06%	150.8	150.9	0.1	0.08%	150.8	150.8	0.0	0.00%	151.08	150.78	-0.20%	150.99	150.78	-0.14%
	2	Clear Sky wo/Hg	0.67	151.0	151.0	0.1	0.06%	150.8	150.7	-0.2	-0.11%	150.7	150.6	-0.1	-0.05%	150.95	150.67	-0.19%	151.05	150.60	-0.30%
		NAAQS	0.67	151.0	151.0	0.0	-0.02%	150.8	150.8	0.0	-0.02%	150.7	150.8	0.1	0.09%	150.98	150.69	-0.19%	150.96	150.82	-0.09%
		Utility Based (Coal)	0.67	150.8	151.0	0.2	0.11%	150.8	150.7	-0.1	-0.04%	150.7	150.7	0.0	-0.01%	150.84	150.70	-0.09%	151.01	150.68	-0.22%
		Utility Based High	0.67	150.8	151.0	0.2	0.11%	150.9	150.9	0.0	-0.02%	150.5	150.5	0.0	-0.02%	150.84	150.50	-0.22%	151.01	150.48	-0.35%
	P(s)	Clear Sky w/Hg	3.17	3256.4	3248.0	-8.3	-0.26%	3240.0	3240.8	0.8	0.02%	3234.5	3230.1	-4.4	-0.14%	3256.35	3234.48	-0.67%	3248.03	3230.09	-0.55%
	3	Clear Sky wo/Hg	3.17	3250.2	3256.2	5.9	0.18%	3243.0	3226.7	-16.3	-0.50%	3213.7	3220.4	6.7	0.21%	3250.23	3213.68	-1.12%	3256.17	3220.39	-1.10%
		NAAQS	3.17	3248.7	3255.3	6.6	0.20%	3237.2	3226.8	-10.4	-0.32%	3217.4	3219.6	2.1	0.07%	3248.70	3217.42	-0.96%	3255.30	3219.56	-1.10%
		Utility Based (Coal)	3.17	3255.7	3254.7	-0.9	-0.03%	3241.5	3233.1	-8.3	-0.26%	3232.5	3227.2	-5.3	-0.16%	3255.69	3232.46	-0.71%	3254.74	3227.16	-0.85%
		Utility Based High	3.17	3255.7	3254.7	-0.9	-0.03%	3224.1	3226.0	1.9	0.06%	3233.8	3221.4	-12.5	-0.39%	3255.69	3233.85	-0.67%	3254.74	3221.37	-1.03%
	P(i)	Clear Sky w/Hg	3.02	5034.3	5012.1	-22.2	-0.44%	4937.1	4938.9	1.8	0.04%	4838.3	4834.9	-3.4	-0.07%	5034.29	4838.29	-3.89%	5012.08	4834.91	-3.53%
	4	Clear Sky wo/Hg	3.02	5021.8	5027.2	5.3	0.11%	4874.6	4889.0	14.4	0.30%	4795.4	4786.3	-9.2	-0.19%	5021.82	4795.42	-4.51%	5027.15	4786.25	-4.79%
		NAAQS	3.02	5041.8	5006.9	-34.8	-0.69%	4861.3	4896.2	34.9	0.72%	4759.0	4769.4	10.4	0.22%	5041.76	4759.00	-5.61%	5006.93	4769.43	-4.74%
		Utility Based (Coal)	3.02	5006.7	5010.2	3.4	0.07%	4838.5	4877.1	38.6	0.80%	4773.2	4755.5	-17.8	-0.37%	5006.75	4773.24	-4.66%	5010.20	4755.47	-5.08%
		Utility Based High	3.02	5006.7	5010.2	3.4	0.07%	4850.8	4840.9	-9.8	-0.20%	4719.1	4733.1	14.1	0.30%	5006.75	4719.07	-5.75%	5010.20	4733.15	-5.53%
	FD(i)	Clear Sky w/Hg	3.03	4982.0	5032.6	40.6	0.81%	4947.6	4948.5	0.9	0.02%	4829.2	4814.5	-14.7	-0.30%	4991.98	4829.23	-3.26%	5032.60	4814.55	-4.33%
	6	Clear Sky wo/Hg	3.03	5007.1	5047.6	40.5	0.81%	4897.4	4874.7	-22.8	-0.46%	4758.0	4824.7	66.7	1.40%	5007.11	4757.98	-4.98%	5047.60	4824.72	-4.42%
		NAAQS	3.03	5030.5	5051.7	21.2	0.42%	4910.1	4921.1	11.0	0.22%	4823.4	4781.6	-41.8	-0.87%	5030.46	4823.35	-4.12%	5051.66	4781.56	-5.38%
		Utility Based (Coal)	3.03	5078.9	5038.7	-40.2	-0.79%	4907.9	4885.7	-22.2	-0.45%	4839.8	4779.3	-60.5	-1.25%	5078.90	4839.77	-4.71%	5038.72	4779.25	-5.15%
		Utility Based High	3.03	5078.9	5038.7	-40.2	-0.79%	4841.9	4860.0	18.1	0.37%	4742.3	4731.0	-11.3	-0.24%	5078.90	4742.33	-5.63%	5038.72	4731.03	-6.11%
	S(s)	Clear Sky w/Hg	2.49	1498.1	1504.2	6.1	0.40%	1492.9	1498.7	5.8	0.39%	1479.6	1485.8	6.2	0.42%	1498.10	1479.57	-1.24%	1504.17	1485.81	-1.22%
	7	Clear Sky wo/Hg	2.49	1486.5	1493.0	6.5	0.44%	1469.1	1474.4	5.3	0.36%	1473.9	1479.4	5.6	0.38%	1486.54	1473.88	-0.85%	1493.02	1479.44	-0.91%
		NAAQS	2.49	1492.9	1502.8	10.0	0.67%	1475.7	1472.3	-3.4	-0.23%	1480.5	1472.6	-7.9	-0.53%	1492.89	1480.52	-0.83%	1502.84	1472.60	-2.01%
		Utility Based (Coal)	2.49	1495.1	1504.7	9.6	0.64%	1489.5	1490.7	1.2	0.08%	1479.3	1484.5	5.2	0.35%	1495.12	1479.33	-1.06%	1504.72	1484.52	-1.34%
		Utility Based High	2.49	1495.1	1504.7	9.6	0.64%	1482.0	1485.2	3.2	0.22%	1474.4	1476.6	2.2	0.15%	1495.12	1474.37	-1.39%	1504.72	1476.57	-1.87%
	S(i)	Clear Sky w/Hg	3.07	5240.5	5271.1	30.6	0.58%	5163.3	5169.1	5.8	0.11%	5073.8	5090.3	16.4	0.32%	5240.47	5073.85	-3.18%	5271.08	5090.26	-3.43%
	8	Clear Sky wo/Hg	3.07	5248.9	5245.8	-3.1	-0.06%	5138.9	5123.7	-15.2	-0.30%	5026.1	5056.2	30.1	0.60%	5248.90	5026.09	-4.24%	5245.77	5056.21	-3.61%
		NAAQS	3.07	5245.8	5296.2	50.4	0.96%	5102.8	5106.8	4.0	0.08%	5010.2	5043.4	33.1	0.66%	5245.76	5010.24	-4.49%	5296.19	5043.38	-4.77%
		Utility Based (Coal)	3.07	5244.2	5269.1	24.8	0.47%	5094.2	5085.7	-8.5	-0.17%	5026.9	5023.0	-3.9	-0.08%	5244.24	5026.92	-4.14%	5269.08	5023.00	-4.67%
		Utility Based High	3.07	5244.2	5269.1	24.8	0.47%	5079.1	5054.2	-24.8	-0.49%	5008.6	5002.5	-6.1	-0.12%	5244.24	5008.62	-4.49%	5269.08	5002.53	-5.06%
	SB(s)	Clear Sky w/Hg	1.61	40.2	41.3	1.1	2.77%	41.4	41.1	-0.4	-0.87%	40.1	40.0	-0.1	-0.29%	40.21	40.10	-0.27%	41.33	39.99	-3.24%
	14	Clear Sky wo/Hg	1.61	40.6	40.0	-0.6	-1.53%	40.3	40.2	-0.1	-0.30%	39.4	39.4	-0.1	-0.14%	40.62	39.42	-2.97%	40.00	39.36	-1.61%
		NAAQS	1.61	40.8	40.8	0.0	0.12%	39.0	39.7	0.7	1.67%	39.5	40.0	0.5	1.37%	40.80	39.48	-3.22%	40.84	40.02	-2.02%
		Utility Based (Coal)	1.61	40.6	40.7	0.1	0.33%	40.0	39.6	-0.3	-0.82%	39.6	39.5	-0.1	-0.31%	40.61	39.58	-2.53%	40.74	39.46	-3.14%
		Utility Based High	1.61	40.6	40.7	0.1	0.33%	39.6	39.2	-0.4	-1.09%	39.3	39.3	0.0	-0.10%	40.61	39.30	-3.24%	40.74	39.26	-3.66%

TABLE 26
Lock Dam 53 Pool
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
L&D 53	ES(s)	Clear Sky w/Hg	0.88	336.0	336.0	0.0	-0.01%	336.8	335.6	-1.2	-0.36%	341.7	339.9	-1.8	-0.52%	335.99	341.65	1.68%	335.96	339.87	1.16%
	1	Clear Sky wo/Hg	0.88	336.1	336.9	0.8	0.25%	335.6	336.4	0.9	0.25%	334.4	335.4	1.0	0.29%	336.07	334.41	-0.49%	336.90	335.38	-0.45%
		NAAQS	0.88	337.6	336.2	-1.4	-0.41%	336.6	337.9	1.2	0.37%	334.9	333.9	-1.0	-0.31%	337.57	334.93	-0.78%	336.19	333.88	-0.69%
		Utility Based (Coal)	0.88	336.1	337.3	1.2	0.35%	338.6	338.2	-0.4	-0.11%	335.5	337.9	2.4	0.71%	336.10	335.51	-0.18%	337.30	337.88	0.17%
		Utility Based High	0.88	336.1	337.3	1.2	0.35%	336.5	339.4	2.9	0.86%	335.8	334.2	-1.6	-0.46%	336.10	335.76	-0.10%	337.30	334.21	-0.91%
	ES(f)	Clear Sky w/Hg	1.17	262.9	262.8	0.0	-0.02%	262.6	262.6	0.0	0.00%	262.3	262.3	0.0	0.01%	262.85	262.31	-0.21%	262.80	262.35	-0.17%
	2	Clear Sky wo/Hg	1.17	262.8	262.9	0.1	0.03%	262.5	262.5	0.0	-0.01%	262.4	262.3	-0.1	-0.04%	262.78	262.41	-0.14%	262.86	262.29	-0.22%
		NAAQS	1.17	262.9	262.8	-0.1	-0.04%	262.6	262.7	0.1	0.05%	262.3	262.4	0.1	0.06%	262.90	262.26	-0.24%	262.78	262.41	-0.14%
		Utility Based (Coal)	1.17	262.7	262.8	0.1	0.03%	262.4	262.5	0.1	0.04%	262.3	262.3	0.0	-0.01%	262.70	262.32	-0.15%	262.78	262.29	-0.19%
		Utility Based High	1.17	262.7	262.8	0.1	0.03%	262.5	262.6	0.1	0.03%	262.3	262.2	-0.1	-0.02%	262.70	262.28	-0.16%	262.78	262.21	-0.22%
	P(s)	Clear Sky w/Hg	5.75	6071.0	6065.1	-5.9	-0.10%	6039.2	6041.1	1.9	0.03%	6013.7	6016.8	3.1	0.05%	6071.02	6013.74	-0.94%	6065.14	6016.79	-0.80%
	3	Clear Sky wo/Hg	5.75	6060.9	6057.9	-3.0	-0.05%	6039.9	6034.6	-5.3	-0.09%	6009.3	6001.8	-7.5	-0.12%	6060.85	6009.29	-0.85%	6057.85	6001.80	-0.93%
		NAAQS	5.75	6054.6	6071.7	17.2	0.28%	6031.0	6026.1	-4.8	-0.08%	5989.9	6007.8	17.9	0.30%	6054.56	5989.90	-1.07%	6071.74	6007.81	-1.05%
		Utility Based (Coal)	5.75	6069.2	6065.8	-3.4	-0.06%	6038.1	6030.9	-7.2	-0.12%	6006.3	6007.8	1.5	0.02%	6069.21	6006.33	-1.04%	6065.79	6007.79	-0.96%
		Utility Based High	5.75	6069.2	6065.8	-3.4	-0.06%	6037.2	6018.8	-18.4	-0.30%	6006.2	6010.6	4.3	0.07%	6069.21	6006.24	-1.04%	6065.79	6010.56	-0.91%
	P(l)	Clear Sky w/Hg	5.36	9178.9	9131.4	-47.5	-0.52%	9025.2	9026.6	1.4	0.02%	8821.9	8824.2	2.3	0.03%	9178.87	8821.93	-3.89%	9131.41	8824.21	-3.36%
	4	Clear Sky wo/Hg	5.36	9172.7	9176.3	3.6	0.04%	8974.1	8975.7	1.7	0.02%	8838.0	8813.4	-24.6	-0.28%	9172.69	8838.04	-3.65%	9176.33	8813.42	-3.95%
		NAAQS	5.36	9200.5	9144.7	-55.8	-0.61%	8972.3	9008.1	35.8	0.40%	8768.5	8780.4	11.9	0.14%	9200.54	8768.53	-4.70%	9144.73	8780.43	-3.98%
		Utility Based (Coal)	5.36	9115.3	9133.4	18.1	0.20%	8919.8	8966.1	46.3	0.52%	8783.3	8762.3	-21.0	-0.24%	9115.33	8783.28	-3.64%	9133.39	8762.26	-4.08%
		Utility Based High	5.36	9115.3	9133.4	18.1	0.20%	8939.6	8930.4	-9.2	-0.10%	8733.9	8739.5	5.6	0.06%	9115.33	8733.91	-4.18%	9133.39	8739.55	-4.31%
	FD(l)	Clear Sky w/Hg	5.37	9122.6	9136.5	13.9	0.15%	9058.5	9048.1	-10.4	-0.11%	8810.9	8777.3	-33.6	-0.38%	9122.55	8810.91	-3.42%	9136.47	8777.34	-3.93%
	6	Clear Sky wo/Hg	5.37	9143.0	9199.8	56.8	0.62%	8977.0	8932.1	-44.9	-0.50%	8770.3	8843.9	73.7	0.84%	9142.98	8770.25	-4.08%	9199.83	8843.93	-3.87%
		NAAQS	5.37	9159.8	9184.9	25.1	0.27%	9012.2	9002.9	-9.4	-0.10%	8874.7	8854.7	-20.0	-0.23%	9159.80	8874.69	-3.11%	9184.90	8854.71	-3.59%
		Utility Based (Coal)	5.37	9221.3	9167.3	-54.0	-0.59%	9005.1	8939.9	-65.2	-0.72%	8872.9	8749.7	-123.2	-1.39%	9221.29	8872.94	-3.78%	9167.32	8749.72	-4.56%
		Utility Based High	5.37	9221.3	9167.3	-54.0	-0.59%	8956.2	8952.1	-4.2	-0.05%	8741.4	8733.9	-7.5	-0.09%	9221.29	8741.40	-5.20%	9167.32	8733.88	-4.73%
	S(s)	Clear Sky w/Hg	3.83	2278.9	2288.9	10.1	0.44%	2267.8	2268.5	0.7	0.03%	2246.9	2246.7	-0.2	-0.01%	2278.88	2246.92	-1.40%	2288.94	2246.70	-1.85%
	7	Clear Sky wo/Hg	3.83	2256.3	2264.3	8.0	0.36%	2239.0	2246.8	7.8	0.35%	2246.0	2253.8	7.8	0.35%	2256.32	2246.02	-0.46%	2264.34	2253.81	-0.46%
		NAAQS	3.83	2270.3	2284.4	14.1	0.62%	2250.3	2243.0	-7.3	-0.32%	2248.8	2234.4	-14.4	-0.64%	2270.30	2248.81	-0.95%	2284.38	2234.41	-2.19%
		Utility Based (Coal)	3.83	2266.4	2268.4	2.0	0.09%	2258.7	2262.3	3.6	0.16%	2243.3	2240.1	-3.2	-0.14%	2266.42	2243.26	-1.02%	2268.43	2240.08	-1.25%
		Utility Based High	3.83	2266.4	2268.4	2.0	0.09%	2246.0	2261.0	15.1	0.67%	2248.3	2237.8	-10.5	-0.47%	2266.42	2248.28	-0.80%	2268.43	2237.78	-1.35%
	S(l)	Clear Sky w/Hg	5.45	9637.9	9662.9	25.0	0.26%	9495.8	9492.5	-3.4	-0.04%	9313.6	9333.8	20.2	0.22%	9637.92	9313.61	-3.36%	9662.91	9333.76	-3.44%
	8	Clear Sky wo/Hg	5.45	9637.8	9626.6	-11.1	-0.12%	9528.3	9456.9	-71.4	-0.75%	9317.1	9361.5	44.5	0.48%	9637.76	9317.06	-3.33%	9626.62	9361.53	-2.75%
		NAAQS	5.45	9634.0	9708.4	74.4	0.77%	9434.8	9430.6	-4.2	-0.04%	9271.2	9318.8	47.7	0.51%	9633.97	9271.18	-3.77%	9708.38	9318.83	-4.01%
		Utility Based (Coal)	5.45	9606.2	9626.0	19.8	0.21%	9417.3	9404.1	-13.2	-0.14%	9271.6	9258.6	-13.0	-0.14%	9606.18	9271.61	-3.48%	9625.95	9258.63	-3.82%
		Utility Based High	5.45	9606.2	9626.0	19.8	0.21%	9413.3	9418.2	4.9	0.05%	9303.6	9290.2	-13.4	-0.14%	9606.18	9303.58	-3.15%	9625.95	9290.16	-3.49%
	SB(s)	Clear Sky w/Hg	1.76	17.7	18.8	1.1	6.34%	19.2	19.1	-0.2	-0.85%	17.4	17.3	-0.1	-0.58%	17.71	17.38	-1.86%	18.83	17.28	-8.24%
	14	Clear Sky wo/Hg	1.76	18.0	17.7	-0.2	-1.22%	17.7	17.4	-0.2	-1.37%	16.9	16.6	-0.3	-1.73%	17.96	16.93	-5.72%	17.74	16.64	-6.21%
		NAAQS	1.76	18.7	18.4	-0.3	-1.49%	16.7	17.0	0.2	1.32%	16.8	17.5	0.7	4.10%	18.68	16.82	-9.98%	18.40	17.50	-4.88%
		Utility Based (Coal)	1.76	18.0	17.5	-0.5	-2.75%	17.7	16.5	-1.1	-6.39%	16.8	16.5	-0.3	-2.04%	18.02	16.83	-6.63%	17.52	16.48	-5.96%
		Utility Based High	1.76	18.0	17.5	-0.5	-2.75%	16.8	16.6	-0.2	-1.24%	16.0	16.4	0.4	2.43%	18.02	16.00	-11.21%	17.52	16.39	-6.48%

TABLE 27
Open River
NAVPAT Data

Pool	Fish Species/ Life Stage[1]	Traffic Forecast Scenario	% of Total River HSI Units	2010				2040				2070				2010-2070			2010-2070		
				Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project HSI Units	With Project HSI Units	Delta	% Delta	Without Project 2010	Without Project 2070	% Delta	With Project 2010	With Project 2070	% Delta
Open River	ES(s)	Clear Sky w/Hg	0.34	131.0	131.2	0.3	0.20%	130.0	129.8	-0.2	-0.16%	131.4	131.8	0.5	0.36%	130.95	131.37	0.32%	131.21	131.85	0.48%
	1	Clear Sky wo/Hg	0.34	130.2	130.8	0.6	0.43%	129.9	130.0	0.1	0.10%	130.6	130.5	-0.1	-0.07%	130.20	130.57	0.29%	130.76	130.48	-0.22%
		NAAQS	0.34	131.8	130.4	-1.3	-0.99%	130.4	130.2	-0.1	-0.11%	130.3	130.1	-0.2	-0.12%	131.75	130.26	-1.14%	130.44	130.10	-0.27%
		Utility Based (Coal)	0.34	131.2	130.4	-0.8	-0.62%	130.1	130.1	0.0	-0.01%	131.3	131.7	0.4	0.32%	131.22	131.26	0.03%	130.40	131.69	0.98%
		Utility Based High	0.34	131.2	130.4	-0.8	-0.62%	130.2	130.6	0.3	0.25%	130.8	130.9	0.1	0.06%	131.22	130.80	-0.32%	130.40	130.88	0.36%
	ES(f)	Clear Sky w/Hg	0.27	61.6	61.6	0.0	-0.01%	61.6	61.6	0.0	0.02%	61.5	61.5	0.0	0.01%	61.64	61.54	-0.16%	61.63	61.55	-0.14%
	2	Clear Sky wo/Hg	0.27	61.6	61.6	0.0	0.00%	61.6	61.6	0.0	-0.04%	61.6	61.6	0.0	0.00%	61.63	61.55	-0.13%	61.63	61.55	-0.13%
		NAAQS	0.27	61.6	61.6	0.0	-0.01%	61.6	61.6	0.0	0.05%	61.5	61.6	0.0	0.03%	61.64	61.55	-0.14%	61.63	61.57	-0.11%
		Utility Based (Coal)	0.27	61.6	61.6	0.0	0.02%	61.6	61.6	0.0	0.04%	61.5	61.5	0.0	-0.01%	61.63	61.54	-0.15%	61.64	61.53	-0.18%
		Utility Based High	0.27	61.6	61.6	0.0	0.02%	61.6	61.6	0.0	0.01%	61.5	61.5	0.0	0.02%	61.63	61.52	-0.17%	61.64	61.54	-0.17%
	P(s)	Clear Sky w/Hg	3.02	3018.7	3018.0	-0.8	-0.02%	3002.8	2999.6	-3.1	-0.10%	2987.7	2989.6	1.9	0.06%	3018.71	2987.71	-1.03%	3017.96	2989.62	-0.94%
	3	Clear Sky wo/Hg	3.02	3015.5	3014.4	-1.1	-0.04%	3002.8	2995.6	-7.1	-0.24%	2981.3	2979.6	-1.7	-0.06%	3015.49	2981.31	-1.13%	3014.37	2979.60	-1.15%
		NAAQS	3.02	3011.0	3024.2	13.2	0.44%	3000.7	2999.2	-1.5	-0.05%	2976.0	2991.8	15.8	0.53%	3011.03	2975.96	-1.16%	3024.24	2991.77	-1.07%
		Utility Based (Coal)	3.02	3023.7	3013.9	-9.8	-0.32%	2997.2	2993.1	-4.1	-0.14%	2979.3	2983.5	4.2	0.14%	3023.68	2979.29	-1.47%	3013.93	2983.46	-1.01%
		Utility Based High	3.02	3023.7	3013.9	-9.8	-0.32%	2999.4	2990.4	-9.1	-0.30%	2985.4	2983.8	-1.6	-0.06%	3023.68	2985.40	-1.27%	3013.93	2983.75	-1.00%
	P(l)	Clear Sky w/Hg	2.94	4919.9	4892.1	-27.8	-0.57%	4816.9	4821.8	4.9	0.10%	4690.9	4686.7	-4.2	-0.09%	4919.89	4690.93	-4.66%	4892.09	4686.74	-4.20%
	4	Clear Sky wo/Hg	2.94	4920.3	4922.7	2.4	0.05%	4783.7	4775.7	-8.0	-0.17%	4700.3	4688.6	-11.7	-0.25%	4920.30	4700.31	-4.47%	4922.70	4688.59	-4.76%
		NAAQS	2.94	4935.2	4899.6	-35.6	-0.72%	4775.8	4796.8	21.0	0.44%	4646.4	4668.4	22.0	0.47%	4935.17	4646.41	-5.83%	4899.56	4668.41	-4.72%
		Utility Based (Coal)	2.94	4875.2	4892.5	17.2	0.35%	4757.3	4779.4	22.1	0.47%	4657.9	4646.4	-11.5	-0.25%	4875.23	4657.93	-4.46%	4892.46	4646.40	-5.03%
		Utility Based High	2.94	4875.2	4892.5	17.2	0.35%	4764.7	4763.3	-1.3	-0.03%	4630.0	4626.2	-3.7	-0.08%	4875.23	4629.98	-5.03%	4892.46	4626.23	-5.44%
	FD(l)	Clear Sky w/Hg	2.94	4892.9	4893.1	0.2	0.00%	4837.7	4823.8	-13.9	-0.29%	4687.5	4658.6	-28.9	-0.62%	4892.86	4687.52	-4.20%	4893.06	4658.63	-4.79%
	6	Clear Sky wo/Hg	2.94	4905.4	4941.8	36.4	0.74%	4790.1	4753.9	-36.2	-0.76%	4662.1	4708.9	46.8	1.00%	4905.44	4662.09	-4.96%	4941.82	4708.92	-4.71%
		NAAQS	2.94	4913.2	4931.6	18.4	0.38%	4812.5	4809.9	-2.6	-0.05%	4733.8	4714.5	-19.4	-0.41%	4913.18	4733.84	-3.65%	4931.62	4714.46	-4.40%
		Utility Based (Coal)	2.94	4953.9	4915.3	-38.6	-0.78%	4802.0	4775.7	-26.3	-0.55%	4726.8	4641.7	-85.0	-1.80%	4953.90	4726.76	-4.59%	4915.28	4641.74	-5.57%
		Utility Based High	2.94	4953.9	4915.3	-38.6	-0.78%	4780.0	4782.5	2.5	0.05%	4641.7	4632.2	-9.5	-0.20%	4953.90	4641.66	-5.39%	4915.28	4632.18	-5.76%
	S(s)	Clear Sky w/Hg	1.02	641.8	642.3	0.5	0.07%	637.0	637.7	0.7	0.11%	635.9	636.5	0.6	0.10%	641.80	635.89	-0.92%	642.28	636.52	-0.90%
	7	Clear Sky wo/Hg	1.02	639.1	639.2	0.1	0.01%	633.3	632.3	-0.9	-0.15%	636.0	637.5	1.4	0.23%	639.11	636.05	-0.48%	639.18	637.50	-0.26%
		NAAQS	1.02	638.6	642.4	3.8	0.60%	635.1	633.0	-2.2	-0.34%	636.8	634.9	-1.9	-0.30%	638.58	636.76	-0.29%	642.42	634.88	-1.17%
		Utility Based (Coal)	1.02	636.6	638.8	2.3	0.36%	635.8	638.2	2.4	0.38%	634.9	634.6	-0.3	-0.04%	636.59	634.92	-0.26%	638.85	634.64	-0.66%
		Utility Based High	1.02	636.6	638.8	2.3	0.36%	635.3	637.3	2.0	0.31%	636.5	634.6	-1.9	-0.30%	636.59	636.51	-0.01%	638.85	634.58	-0.67%
	S(l)	Clear Sky w/Hg	2.99	5191.2	5207.1	15.9	0.31%	5094.2	5092.7	-1.5	-0.03%	4975.0	4987.5	12.5	0.25%	5191.21	4975.03	-4.16%	5207.09	4987.53	-4.22%
	8	Clear Sky wo/Hg	2.99	5193.5	5186.1	-7.4	-0.14%	5109.1	5064.4	-44.7	-0.87%	4978.1	5009.7	31.6	0.64%	5193.52	4978.08	-4.15%	5186.15	5009.72	-3.40%
		NAAQS	2.99	5188.5	5241.7	53.2	1.03%	5050.8	5043.6	-7.2	-0.14%	4952.2	4985.3	33.1	0.67%	5188.52	4952.16	-4.55%	5241.74	4985.31	-4.89%
		Utility Based (Coal)	2.99	5168.8	5184.7	15.9	0.31%	5041.6	5037.1	-4.4	-0.09%	4942.9	4937.4	-5.5	-0.11%	5168.78	4942.86	-4.37%	5184.68	4937.36	-4.77%
		Utility Based High	2.99	5168.8	5184.7	15.9	0.31%	5040.1	5046.7	6.6	0.13%	4967.8	4959.9	-7.9	-0.16%	5168.78	4967.83	-3.89%	5184.68	4959.94	-4.33%
	SB(s)	Clear Sky w/Hg	0.63	6.3	6.7	0.4	5.60%	6.1	6.2	0.1	2.37%	6.2	5.9	-0.4	-5.80%	6.35	6.25	-1.52%	6.70	5.89	-12.15%
	14	Clear Sky wo/Hg	0.63	6.3	6.4	0.0	0.78%	6.2	6.1	-0.1	-1.53%	6.1	6.1	0.1	1.00%	6.32	6.07	-3.91%	6.36	6.13	-3.70%
		NAAQS	0.63	6.3	6.4	0.1	1.45%	5.9	6.0	0.1	2.40%	5.9	6.1	0.2	3.60%	6.26	5.89	-5.94%	6.35	6.11	-3.85%
		Utility Based (Coal)	0.63	6.3	6.3	0.0	0.01%	6.2	6.0	-0.2	-2.49%	6.0	5.7	-0.2	-3.91%	6.31	5.96	-5.66%	6.31	5.73	-9.26%
		Utility Based High	0.63	6.3	6.3	0.0	0.01%	5.8	5.7	-0.1	-1.58%	6.0	6.2	0.2	3.35%	6.31	5.96	-5.57%	6.31	6.16	-2.41%

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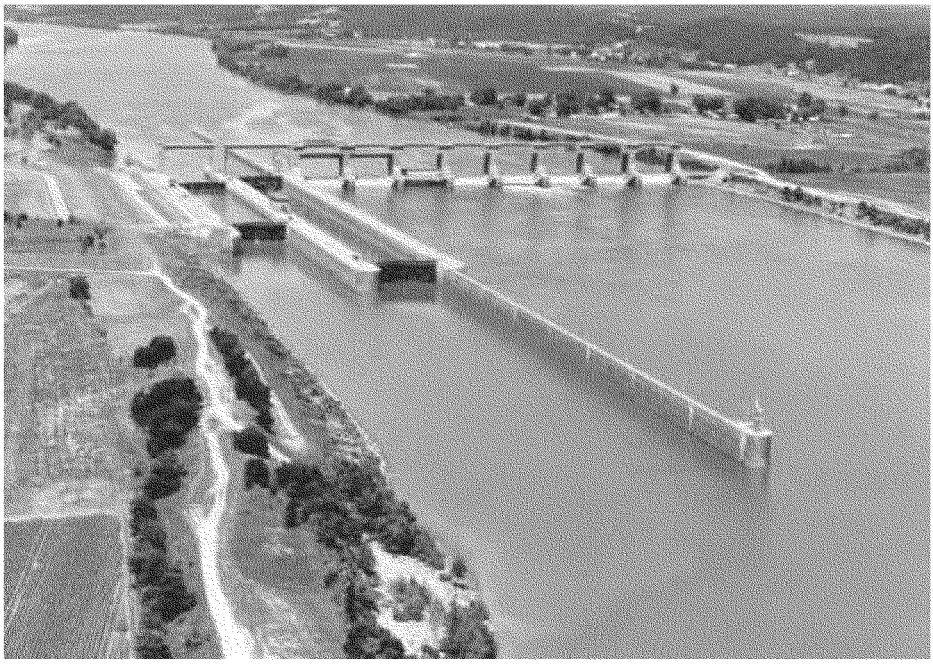
Upstream Fish-Passage Opportunities at Ohio River Mainstem Dams



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Cover photo: Arial photograph of the Belleville Dam on the Ohio River near Reedsville, Ohio. File Photo U.S. Army Corps of Engineers.

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Abstract

Mainstem dams on the Ohio River may affect the bioproduction and biodiversity of native fishes by imposing restrictions to natural longitudinal movements. Literature on native fishes in the Ohio River suggests that many of these species are migratory during the reproductive phase of their life cycles or move longitudinally between feeding and overwintering areas at other times. If mainstem dams pose restrictions to these migrations or movements, populations may be affected by failed or reduced reproduction and increased mortality related to poor habitat. As well, increased isolation of subpopulations and reduced habitat availability brought about by restricted movements can negatively affect metapopulations of large river fishes by increasing the likelihood of local extinctions and reducing re-establishment rates. The objective of our study was to assess upstream fish-passage opportunities through Ohio River mainstem dams by relating historical hydraulic conditions at these dams to swimming capabilities of select native and non-native fishes to determine if these dams are restricting upstream movements of fishes. Additionally, abundance and distribution of target species were examined in relation to upstream fish-passage opportunities at mainstem dams to determine if restricted fish passage might influence these factors. Fish species included in this study were selected based on consultation with the Ohio River Mainstem Study-Environmental Team and review of pertinent literature on the migratory behaviors of native and non-native fish species in the Ohio River. A comparison of the swimming speeds of target fishes with estimated water velocities through the gates of mainstem dams during various conditions, and reports of upstream movement of target fishes through dams suggest that upstream fish passage opportunities generally occur during open-river rather than controlled conditions at dams. Open river is the condition when the dam gates have been lifted clear of the water and are no longer controlling water levels behind the dam; at open river, the water surface elevation immediately downstream of the dam (i.e., tailwater) is about equal to the water surface elevation immediately upstream of the dam (i.e., headwater). An analysis of historical water elevation data at Ohio River mainstem dams revealed that the frequency of open river by calendar week and hence the potential for fish passage varied spatially along the river by dam and temporally with discharge. The general spatial pattern of open river indicated that the potential for fish passage is low to high at dams in the Louisville District, low to moderate at Huntington District dams, and low at Pittsburgh District dams. In general, open-river conditions were more frequent during winter and spring (i.e., high-flow period; December through June) and generally nonexistent during summer and fall (i.e., low-flow period). Pre- and post-dam abundance and distribution information for target species, along with life history information suggest that some species are affected by mainstem dams on the Ohio River. Uncertainty as to the role of mainstem dams in the reduction in abundance and distribution of target species remains because of the qualitative nature of the data and because concomitant stressors have acted upon these species. However, there is a growing recognition that efforts will need to go beyond species- and site-specific management to restore the natural bioproductivity and biodiversity of large regulated rivers. River systems are large complex ecosystems necessitating restoration efforts at comparable scales and complexities followed by long-term assessment and adaptive management. To be successful, these efforts will need to focus on systemic issues including the restoration of more natural flow regimes, floodplain connectivity, water and substrate quality, and fish passage.

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Introduction

The Ohio River has 20 mainstem dams (Figure 1) that influence the ecology of the river. Recent literature on ecological concepts for large rivers suggests that longitudinal connectivity is an important feature in regards to ecosystem structure and function (e.g., Vannote et al. 1980; Ward and Stanford 1995), and hence restoration of large rivers (Stanford et al. 1996). This is obviously true in regards to the restoration of large river fishes with life-stage specific habitats that are spatially separated along a river system, or when metapopulation structure is important for sustaining a species in a system (Stanford et al. 1996). A well-touted example of the consequence of dams to fish populations in large rivers is the loss of salmon stocks in the Columbia River Basin, where more than 200 stocks of anadromous salmonids have become extinct (Bergkamp et al. 2000).

Numerous studies indicate that longitudinal connectivity may be equally important to some species of non-salmonid, both potadromous and diadromous, fishes inhabiting large floodplain rivers (e.g., sturgeons, paddlefish *Polyodon spathula*, and herrings; Auer 1996; Johnson et al. 1997; Bergkamp et al. 2000). If these fish are intermittently or completely denied access to spawning habitats or delayed from reaching these habitats because of dams, variable recruitment and possibly extirpation of existing stocks may result. Pearson and Pearson (1989) stated that the Ohio River mainstem dams eliminated the spring run of Alabama shad *Alosa alabamae* and seriously impaired movements of other fishes. The degree to which loss of longitudinal connectivity affects population levels of large-river, non-salmonid fishes is probably species and system specific, and is generally unknown because of the difficulty in assessing population levels and because other factors (e.g., habitat alterations and pollution) concomitantly influence these populations.

Longitudinal movements of fish within a large river system may serve other ecological functions. One example is that fish movement serves as a dispersal mechanism for juvenile freshwater mussels. Freshwater mussels, including those in the Ohio River Basin, are recognized as one of the most threatened fauna in North America. Eleven of 127 species of freshwater mussels in the Ohio River have gone extinct since the turn of the 19th century; 46 of the remaining species are considered endangered or species of concern (Neves 1999). In general, freshwater mussels have an obligate parasitic stage during which they are attached to the gills of a specific host fish species. If fishes are prevented from moving upstream during critical life stages of mussels then this mechanism of development and dispersal is disrupted and can lead to complete recruitment failure for affected species and possibly extirpation. For example, Upper Mississippi River dams are thought to have contributed to the decline of the ebony shell *Fusconaia ebena* and elephant ear *Elliptio crassidens* mussel by blocking movements of the skipjack herring *Alosa chrysochloris*, a primary host species for the two mussel species (Becker 1983; U.S. Fish and Wildlife Service 1999).

Anecdotal and scientific information suggest that some fish species (e.g., paddlefish and sauger *Stizostedion canadense*) pass upstream through Ohio River mainstem dams (Johnson et al. 1997; Conover and Grady 2000; Henley et al. 2001; C. O'Bara, West Virginia Department of Natural Resources, Parkersburg, West Virginia, personal communications). As well, numerous fish species that are common to the Ohio and Mississippi Rivers are known to pass upstream through Mississippi River dams (Holland et al. 1984) that are similar in design in terms of pathways for upstream fish passage to Ohio River dams. To pass upstream through Ohio River dams, fish must move through one of the major sections of the dam, that is through

the controlled (i.e., gated) section, over the uncontrolled section (i.e., fixed weir), or through one of the lock chambers. Fish passage opportunities probably change temporally with discharge because hydraulic conditions, that is lift and water velocity, at or through these dam sections change with discharge. Lift is the difference between water surface elevation immediately upstream (headwater) and immediately downstream (tailwater) of the dam. Also discharge, lift, and dam section dimensions vary among Ohio River mainstem dams probably resulting in spatial variation in fish-passage opportunities along the river.

Wilcox et al. (unpublished report) examined the temporal and spatial patterns of fish-passage opportunities at Mississippi River navigation dams (27 mainstem dams) by comparing fish swimming abilities with hydraulic conditions at these dams. Their study concluded that water velocities through the dam gates probably impede fish moving upstream during most of the year, and that the best opportunity for fish passage occurs when dam gates are completely out of the water, that is during open river. Their study suggests that fish-passage opportunities are species and dam specific and that operational or structural modifications should be investigated to determine if fish-passage opportunities can be enhanced.

A systematic evaluation of fish-passage opportunities at the 20 navigation dams along the 1,578-km length of the Ohio River has not been conducted, but is warranted given the findings of Wilcox et al. (unpublished report). The Ohio River differs from the Upper Mississippi River in regards to fish fauna, mainstem dam dimensions, channel morphology, and discharge regime. Thus, the findings of Wilcox et al. (unpublished report) are not wholly applicable to the Ohio River.

The objective of our study was to assess upstream fish-passage opportunities through Ohio River mainstem dams by relating historical hydraulic conditions at these dams to migration timing and swimming capabilities of select native and non-native fishes. Additionally, migratory behavior and post-dam abundance and distribution of these species were examined in relation to fish-passage opportunities. Fish species included in this study (Table 1) were selected based on consultation with the Ohio River Mainstem Study (ORMSS)-Environmental Team (i.e., biologists familiar with the fish and fisheries in the Ohio River) and review of pertinent literature on the migratory behaviors of native and non-native fish species in the Ohio River.

Study Area

The Ohio River flows 1,578 km from its source at the confluence of the Allegheny and Monongahela Rivers near Pittsburgh, Pennsylvania to its confluence with the Mississippi River near Cairo, Illinois (Figure 1). At the upper end near Sewickley, Pennsylvania, the mean discharge ranges from about 400 m^3/s in October to 2,200 m^3/s in March (Figure 2; raw data from the U.S. Geological Survey database at www.water.usgs.gov/nwis/discharge). At the lower end near Metropolis, Illinois, the mean discharge ranges from about 2,600 m^3/s in September to 15,800 m^3/s in March. As well, channel and floodplain width and stream gradient vary substantially from source to mouth (Table 2; after Pearson 1992).

Frost and Mitsch (1989) described the modern day Ohio River with its navigation dams as resembling a series of connected lakes more than a river. The navigation pools (i.e., impoundments) formed behind the mainstem dams range in length from about 11 km (Dashields Pool) to more than 180 km (Cannelton Pool; Tables 3a–3c). The upper ten pools (Emsworth to R. C. Byrd Pools) average 48 km (range 11 to 72 km) in length, while the remaining downstream pools, excluding pools for Dams 52 and 53 (each about 30 km long),

average 126 km (90 to 183 km) in length (8 pools). Water velocities in these navigation pools are reduced at normal discharges as compared to the predammed river and may be negligible during low-water periods (Taylor 1989) in some pools. Van Hassel et al. (1988) noted that this conversion of lotic areas to lentic areas is an important factor that has influenced fish communities in the Ohio River. Numerous tributaries flow into the navigation pools of the Ohio River along its 1,578 km course (Table 4; also see Henley et al. 2001). The largest tributaries are in the lower reach of the river and include the Tennessee, Cumberland, and Wabash Rivers. The reservoirs on the tributaries impact the discharge and water quality of the mainstem Ohio River. Pearson (1992) summarized the three major effects as (1) water storage that reduces the maximum seasonal flow rates and lengthens the duration of bank-full stages (2) low flows during droughts are nearly twice those before impoundment and (3) the water released to the mainstem from the reservoirs is often less turbid than before.

Significant system modifications to accommodate commercial navigation on the mainstem of the Ohio River have included snag removal, dredging, and construction of wing dikes, back channel dikes, and canals in the early to mid-1800s; construction of low-lift dams (more than 50 dams, mostly removable wicket-type) in the late 1800s and early 1900s; and most recently (i.e., 1920s to 1980s) completion or modification of 18 high-lift dams and associated locks (Tables 3a-3c; Pearson and Krumholz 1984; Frost and Mitsch 1989; U.S. Army Corps of Engineers 2002). At present, 20 mainstem dams (18 high-lift and two movable low-lift, wicket type) with lifts ranging from 3.3 to 12.3 m are in place on the Ohio River mainstem (Figure 1). The 20 existing dams, in conjunction with dredging, help maintain a minimum 2.7-m navigation channel throughout the Ohio River. A new high-lift dam (i.e., Olmstead Dam) is being constructed at ORKm 1,552 (Ohio River Kilometer measured from the source of the Ohio River at the confluence of the Allegany and Monongahela Rivers) to replace the two remaining wicket dams (i.e., Dams 52 and 53). This new dam will have a lift of 8 m and is scheduled for completion in 2010.

Mainstem Dams

Design characteristics—The 20 mainstem dams on the Ohio River were completed over a 60-year period (i.e., 1921 to 1980) and are dispersed along a 1,500-km reach of a heterogeneous river channel. Thus, the features of these dams differ in terms of lift, total span, and span and type of controlled (i.e., gated) and uncontrolled (i.e., fixed-weir) sections (Tables 3a-3c). The "typical" high-lift dam includes a gated and fixed-weir section on the main channel of the river, along with a pair of locks (Figure 3). The span of the dams, including gated and fixed-weir sections perpendicular to the main flow, locks, and hydropower facilities (excluding islands), varies from about 360 to 800 m. The gated sections of the dams span about 285 to 425 m, and usually consist of multiple (i.e., 4 to 12) tainter gates (e.g., Figure 4) with individual widths of 30.5 to 33.5 m. The gated sections of two dams, Emsworth and Montgomery Dams, have Sydney-type gates (e.g., Figure 5; 14 and 10 gates, respectively) with gate-widths of 30.5 m. Emsworth Dam includes a gated section in the main (8 gates) and back channel (6 gates). The R. C. Byrd Dam differs from the typical high-lift dam in that it has a gated section consisting of eight roller gates (e.g., Figure 5) with widths of 38.1 m, and no fixed-weir section. Other high-lift dams that lack a fixed weir include Markland, Racine, and New Cumberland Dams. Conversely, Dashshields Dam is a fixed weir (483.1 m long) without a gated section. Fixed-weir sections (e.g., Figure 6) on the main channel of the other high-lift dams, excluding McAlpine

Dam, have spans of 10.5 to 682.4 m. The 2,500-m fixed weir at McAlpine Dam includes a 2,000-m section that parallels the main flow and surrounds the Falls of Ohio Wildlife Conservation Area. The lock chambers for this dam are also non-typical in that they are located in a canal that was originally built in 1830 to bypass the Falls of Ohio rather than in the main channel. The fixed-weir sections of the Smithland, J. T. Myers, and Newburgh Dams are navigable fixed weirs that can be traversed by vessels during high river stages (Tables 3a-3c). This is not so for other dams that have non-navigable fixed weirs.

The two remaining mainstem dams, Dams 52 and 53, are low-lift, movable-wicket dams. These dams consist of a controlled section about 1,000 m wide and a set of locks. The controlled portion of these dams consist of a series of movable sections (i.e., wickets; Figure 6) that are lifted to a vertical position by a manned vessel and crane system during low-water periods to form a low-head dam across the channel. Vessels traveling on the river when this low-head dam is present (i.e., wickets in vertical position) must use the lock system. When water levels are high, that is deep enough to allow navigation above that point on the river without a low-head dam, the wickets are laid down horizontally onto the river bottom. When the wickets are in this horizontal position, vessels can travel up and down the river by passing directly over the wickets, thus bypassing the locks.

Fish passage through dams—At low to moderate discharges, that is normal-flow conditions, there is a lift at the dam. For typical Ohio River mainstem dams under normal-flow conditions, most water passes under the dam gates. This type of flow is submerged-orifice flow, and the discharge and water velocity through this submerged-orifice is dependent on the size and character (e.g., sharp or rounded entrance) of the gate opening, and the amount of lift at the dam (Alexander 1992; Corsi and Schuler 1995). Under normal-flow conditions, fish must swim through these gate openings to pass upstream through the dam, or alternatively must move through the locks. Upstream fish passage is probably precluded at the fixed weir under normal-flow conditions because of the lift at the dam. With lift at the dam, either there is no flow or cascading flow over the weir depending on the elevation of the weir crest relative to the normal controlled pool elevation above the dam.

As discharge increases to high-flow conditions, the lift at a typical dam approaches a minimum (i.e., tailwater elevation nearly equal to headwater elevation), and the gates of the controlled section are lifted completely out of the water; this condition is commonly referred to as open river. During open river, fish must swim through the now open, gated section or over the fixed weir to pass the dam. Under these conditions, fish passage is probably dependent on the water velocities through the open gates or over the fixed weir. The magnitudes of these velocities are dependent on the slope of the water across the dam and characteristics of the weir, rather than on the lift and gate opening characteristics as with submerged-orifice flow. As water elevation continues to rise with discharge past the initial open-river point, other areas (i.e., inundated floodplain) become available for fish passage.

Notable exceptions to the typical Ohio River dam include Dams 52 and 53 (wicket dams) and Dashields Dam (fixed weir only). When lift is present at these dams, the only route for fish passage is through the lock chambers because there is no gated section; during open river (i.e., essentially no lift) fish must pass over the navigable-pass (Dams 52 and 53) or fixed-weir (Dashields Dam) sections. As well, at low discharges at dams with hydroelectric facilities (Tables 3a-3c), most water passes through the turbines rather than under the gates.

Fish passage through locks during normal operations probably occurs at normal and high flows, but is not likely a major passageway for fish given unsuitable flow patterns through and around the lock chambers during normal operations (Wilcox et al. unpublished report). That is, the flow patterns are not conducive for attracting fish into or leading them out of the lock chamber under normal operations. Methods to successfully attract fish into the lock chamber by manipulating the lock gates and the fill and drain system to establish attractant flow patterns have been demonstrated (Ohio River Valley Water Sanitation Commission {ORSANCO} 1962). However, the efficiency (i.e., ratio of the number of fish entering the chamber from downstream to the number of fish moving upstream out of the lock chamber) of these methods to pass fish through the dams has not been determined.

Methods

Fish passage opportunities—A comparison of fish swimming speeds to water velocities in the gate openings was made to determine the hydraulic conditions, that is the critical lift, that allows target fish to pass through the gates of Ohio River mainstem dams. As an index of fish-passage opportunities at each dam, the frequency of occurrence of critical lift was determined by examining historical water-surface elevation (i.e., headwater and tailwater) data for each dam.

Life history information—To assess swimming abilities and passage opportunities of target fishes during spawning-migration periods, pertinent life history information was extracted from relevant literature. Life history information, including adult sizes and spawning temperatures, was obtained largely from fishery textbooks; data from proximal sources such as Trautman (1981), Wallus et al. (1990), Clay (1975), Smith (1979), and Forbes and Richardson (1920) were examined first to obtain Ohio River-specific information. Median adult size was recorded as the median total length reported for mature fish across sources. Spawning temperatures of target fishes were defined as the range of temperatures reported in the literature for ripe, spawning, or nest guarding individuals.

Spawning-migration periods were estimated for target fishes based on season and reported water temperatures during spawning. The migration periods for target species were defined as the spawning periods (i.e., the period when water temperatures in the Ohio River were equal to the reported spawning temperatures) and the four weeks before the spawning period. The weekly average water temperature at Ohio River dams was determined with data from four sites on the Ohio River including Evansville, Indiana; South Heights, Pennsylvania; Joppa, Illinois; and Wheeling, West Virginia (Table 5). Mean temperature for each calendar week was determined for these four sites and then used to estimate weekly average water temperatures at each dam by linearly interpolating between sites by river kilometer.

Swimming speeds—Literature searches to obtain swimming speed information were conducted on Web-based sources including a fish-passage bibliography (Ickes et al. 2001), Cambridge Scientific Abstracts (2003), and FishBase (2003). Ickes et al. (2001) contains nearly 500 citations relevant to fish passage in large floodplain rivers. Cambridge Scientific Abstracts includes coverage of the Aquatic Science and Fisheries Abstracts Series that monitors more than 5,000 publications. FishBase (2003) includes referenced information on more than 26,000 fish species.

Many techniques have been used to quantify fish swimming speeds; Bainbridge (1958) and Videler (1993) give details on many of these. Fish swimming speeds are usually expressed as sustained, prolonged, or burst speeds. Generally, sustained speeds are considered speeds that a fish can maintain for greater than 200 min and entail the use of red muscle fibers and aerobic metabolism by fish (Jones 1982). Burst speeds are the maximum speed a fish can maintain for about 15 s before exhaustion (Blake 1983). Burst swimming is an anaerobic process that generally entails the use of white muscle fibers (Blake 1983). Prolong swimming speeds generally fall between sustained and burst speeds. This type of swimming entails red and white muscle fiber use and requires aerobic and anaerobic metabolism (Blake 1983). Like burst swimming trials, experiments to establish prolonged speeds end with complete exhaustion of the fish. Prolonged swimming speeds are often referred to as critical swimming speeds (Brett 1964), and are commonly expressed as $Ucrit_{10}$, where $Ucrit_{10}$ is the speed a fish can maintain for 10 min before exhaustion.

Information on prolonged and burst swimming speeds was summarized from the literature. If species-specific information on prolonged and burst swimming speed of target fishes was not available, then information from morphologically similar species (i.e., a surrogate) was used if available. Often times swimming speed data reported in the literature are based on subadult fish or water temperatures differing from migration temperatures. For this study, direct observations and empirically derived models were interpreted to estimate swimming speeds for median adult-sized fish at median migration temperatures when possible.

To obtain an estimate of burst swimming speed for all target species at the median adult length and spawning-migration temperature, maximum swimming speeds (U_{max}) were calculated with the method derived by Winter and Van Densen (2001). They used U_{max} as a proxy for burst swimming speed for a variety of fishes when estimating fish passage opportunities through weirs in the River Vecht. U_{max} was determined with

$$U_{max} = SlF_{max} \qquad (1)$$

where S is the stride length or the maximum distance a fish travels in one tail beat expressed as a proportion of the fish's total length, l is the total length of the fish, and F_{max} is maximum tail beat frequency in beats per second (Blake 1983; Videler 1993). For example, the estimated burst swimming speed for a 0.20-m fish with a stride length of 0.7, and F_{max} of 15 is 2.1 m/s.

The two kinematic variables controlling U_{max} in fishes are S and F_{max}. While species-specific kinematic data are not available for most fish species, it seems reasonable that S and F_{max} data from other species with similar morphology and thus swimming form could be used to estimate these parameters for species lacking data (Winter and Van Densen 2001). Videler (1993) found that stride length varies little among fishes with carangiform and subcarangiform swimming modes, which are the modes used by most Ohio River target species. Based on Videler (1993) and Winter and Van Densen (2001), 0.7 was used as an estimate of stride length for most target species in our study; exceptions included angullids, esocids, and gars (Table 6).

Maximum tail beat frequency (F_{max}) is species, size, and temperature dependent (Videler 1993). Target species in our study were placed into one of three general F_{max} groups based on species after Winter and Van Densen (2001) including (1) high F_{max} (i.e., 25 Hz), includes the rheophilic catostomids, clupeids, piscivorous percids, esocids, percicthyids, and hiodontids (2) intermediate F_{max} (i.e., 20 Hz), includes ictalurids, centrarchids, and sciaenids or (3) low F_{max}

(i.e., 15 Hz), includes high-bodied cyprinids and catostomids, anguillids, polydontids, and acipenserids (Table 6). These F_{max} values are for a standard water temperature of 15°C and standard fish size of 9, 8, and 7 cm, respectively for the three groups (i.e., 25, 20, and 15 Hz). The F_{max} values were adjusted for species-specific median adult length and median water temperature during migration periods with

$$F_{lt} = F_{xy}\,(0.87^{(l-x)/10})(2^{(t-y)/10}) \qquad (2)$$

where F_{lt} is length and temperature adjusted F_{max}, and F_{xy} is F_{max} for a target species based on the group (i.e., 15, 20, or 25 Hz). In accordance with this equation, F_{max} doubles for each 10°C increase in temperature and decreases by a factor of 0.87 for each 10-cm increase in total length. Some researchers have noted that burst speeds do not change with water temperature (Blaxter 1969; Peake et al. 1997), thus F_{max} was also calculated for each species at 15°C (i.e., without adjusting for migration temperature).

Water velocities through dam gates—The average water velocity through gate openings at various lift across the dam was estimated with a standard hydraulic equation (Equation 3). For submerged-orifice flows, this equation assumes that flow is uniform through the gate opening and that mass and energy are balanced between the approach-section and the section just downstream of the gate (Alexander 1992). Water velocity estimates through gate openings were made for Ohio River mainstem dams in which complete gate schedules were available from the U.S. Army Corps of Engineers (i.e., Emsworth, Montgomery, New Cumberland, Pike Island, Hannibal, and Greenup Dams). Gate schedules included the hydraulic variables needed to solve the standard equation. This equation incorporates the dimensions of water flow through the dam gates and the total discharge to estimate average water velocity through the gates as

$$V = Q/(h*w) \qquad (3)$$

where V is average water velocity in the gate openings, Q is the total discharge through the dam, h is the sum of the all gate opening heights, and w is the average width of the gates. Where gate schedules indicated that the gates were fully open, individual gate opening height was assumed to be equal to the normal pool elevation minus gate sill elevation (i.e., the height of water flowing through the open gate) rather than the assumed opening height given on the gate schedule.

For comparison, water velocities through gates at a mainstem dam on the Upper Mississippi River (i.e., Lock and Dam 7) were also determined with Equation 3, except that the discharges through individual gates were estimated with the two-point, current-meter method (Corsi and Schuler 1995), rather than from gate schedules. In this method, V in Equation 3 is the average water velocity through the gate, h is the height of the gate opening, and w is the width of the gate opening. Additionally, information from two hydraulic studies of Upper Mississippi River dams (Alexander 1992; Osvalt and Grace unpublished data) was used to describe magnitudes and patterns of water velocities through gate bays.

Frequency of open river—Synthesis of information on fish swimming speeds and magnitudes and patterns of water velocities through gates indicated that the lift most likely to allow fish to pass through dams was the minimum lift (see Results). This minimum lift, known as swellhead, occurs at a dam during open river when gates are lifted completely out of the water. Lift

remaining at open river results from the slope of the riverbed between the tailwater and headwater gages, and any backup of the water at the dam structure because of a reduction in the effective channel width.

As an index of fish-passage opportunities by week of year, the daily tailwater elevation data (Table 7) for each Ohio River mainstem dam were analyzed to determine the proportion of years a particular calendar week was at open river. For example, if 5 of the 20 years of historical data for week 14 (i.e., about the second week in April, 1981 to 2000) indicate that the dam was open, then the proportion of years in which suitable fish-passage conditions existed at that dam for week 14 is 25%. For a week to be considered as an open-river week in the frequency analysis, the dam had to be open for at least one day during the week. A dam was assumed to be at open river on a given day if the tailwater elevation at that dam was greater than or equal to the normal pool elevation minus an estimate of swellhead for that dam. A jump in the cumulative frequency distribution for lift just above zero is indicative of swellhead (Figures 7a-7c). However, for many dams swellhead could not be determined because of infrequent open-river conditions at the dams; in these instances, a value of 0.153 m was used as an estimate of swellhead (Table 7).

Daily water-surface elevation data were available for 20 to 26 years (post-dam completion) for all dams except Emsworth Dam (Table 7). Water elevation data for Emsworth Dam were available for 1995 to 2000. Some daily headwater or tailwater elevation data were missing for other dams during these periods. Missing tailwater values for a particular dam, including values for Emsworth Dam between 1980 and 1994, were estimated with linear regression analysis on available elevation data for that dam and concurrent data from an upstream or downstream dam. For example, missing tailwater elevation data for Emsworth Dam were estimated by determining the relation between Emsworth Dam tailwater elevations 1995 to 2000 and Dashields Dam tailwater elevations 1995 to 2000, and then interpreting this relation to estimate missing Emsworth Dam tailwater elevations from 1980 to 1994. Headwater (i.e., pool) elevations are controlled within a specified range at normal flows and thus missing values could not be estimated in a similar manner as tailwater elevations. Tailwater elevation data for Dams 52 and 53 were missing on numerous days for the period of record; missing daily values for tailwater elevation from these dams were assumed to signify that the dams were at open-river condition on those days when values were missing based on communications with Bill Byron, U.S. Army Corps of Engineers, Louisville District.

Abundance and distribution of target fishes—Spatial and temporal abundance and distribution information and information on swimming and migratory behaviors were collected for target species from relevant literature. In addition, literature from a bibliography compiled by the ORMSS-Environmental Team on natural resources of the Ohio River was used to obtain references on agency reports and unpublished data pertinent to abundance and distribution of target species. Pearson and Pearson (1989; update to Pearson and Krumholz 1984) summarized abundance and distribution information by river reach (upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) and period (1900 to 1969 and 1970 to 1988) for all target species. To assess more recent (i.e., 1989 to 2001) abundance and distribution, two data sets with catch information (i.e., ORSANCO unpublished data; Ohio Environmental Protection Agency [OEPA] unpublished data) were analyzed to determine frequency of occurrence of target species in samples. Occurrence classes included common (i.e., occurs in >50% of samples); occasional (i.e., occurs in >15% to =50% of samples;

uncommon (i.e., occurs in ≤15% of samples); or absent (i.e., did not occur in any samples). For this analysis, lock rotenone samples (ORSANCO unpublished data) from a given lock were considered to be from that dam's navigation pool, and night electrofishing samples (OEPA unpublished data) from the same navigation pool during a given year were considered as one sample. For the results and discussion sections of this report, we adopted Pearson and Pearson's (1989) definitions of river reaches (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) unless otherwise specified.

Results

Swimming speeds—Prolonged swimming speeds of median-size adults derived from species-specific observations or empirical models were available for 15 of 44 target species (Table 8). The range of prolonged speeds for these species was 0.45 to 0.88 m/s. Information from seven surrogate species (six target, one nontarget; see Appendix A for scientific names of nontarget surrogates) were used to estimate prolonged speed for 28 target species. The prolonged swimming speed of the American eel *Anguilla rostrata* was not estimated because information was not available. Prolonged swimming speeds including surrogate-derived estimates ranged from 0.45 to 1.02 m/s with only one value exceeding those from species-specific information (i.e., 1.02 m/s for blue sucker *Cycleptus elongates*; longnose sucker *Catostomus catostomus* surrogate). Only four species had estimated prolonged swimming speeds of less than 0.60 m/s, including northern pike *Esox lucius* (0.45 m/s), silver redhorse *Moxostoma anisurum* (0.54 m/s), longnose gar *Lepisosteus osseus* (0.45 m/s), and shortnose gar *Lepisosteus platostomus* (0.45 m/s).

Estimates of burst speeds derived from species-specific observations or empirical models were made for 6 of 44 target species (Table 8). Estimates ranged from 1.00 to 4.73 m/s. Two estimates of burst speed were available for northern pike (i.e., 2.50 and 4.68 m/s) and common carp *Cyprinus carpio* (1.17 and 1.75 m/s). Excluding the two highest burst speeds for northern pike (i.e., 4.68 m/s) and alewife *Alosa pseudoharengus* (i.e, 4.73 m/s), values ranged from 1.00 to 2.50 m/s. Eight surrogate species (four target and four nontarget) were used to estimate burst speeds of 32 target species. The range of burst speeds including surrogate-derived estimates was the same as that for species-specific estimates (i.e., 1.00 to 4.73 m/s). Estimates of burst speed were not made for seven target species because information was not available. Estimates of maximum swimming speed from Equation 1 (i.e., proxy for burst speed; U_{max}; Winter and Van Densen 2001) were made for all target species (Table 8). These values ranged from 1.55 to 5.22 m/s at a standard temperature of 15°C ($U_{max\text{-}15}$) and 1.00 to 7.38 m/s at median temperature during spawning migrations ($U_{max\text{-}t}$).

Water velocities through dam gates—Average water velocities, estimated with Equation 3, through gates of Ohio River mainstem dams (i.e., Emsworth, Montgomery, Pike Island, New Cumberland, Hannibal and Greenup Dams) ranged from 2.14 m/s at 0.31 m of lift to 13.67 m/s at 8.14 m of lift (Figure 8); the minimum and maximum estimated water velocities occurred at the Greenup Dam. The minimum water velocities through the gate openings occurred at the minimum lift when gates were completely out of the water (i.e., open river). Water velocities at minimum lift for these six mainstem dams averaged 2.68 m/s (standard deviation = 0.51 m/s) and ranged from 2.14 to 3.58 m/s. Excluding Emsworth and Montgomery Dams, where minimum head at open river was relatively high (i.e., 1.80 and 0.67 m, respectively) minimum water

velocities ranged from 2.14 to 2.68 m/s at lift of 0.23 to 0.34 m. Estimated water velocities through roller and tainter gates at Lock and Dam 7 on the Upper Mississippi River were similar to velocities at Ohio River dams and ranged from 2.6 m/s at 0.4 m of lift to 7.7 m/s at 2 m of lift (Figure 8). Water velocities through other Ohio River mainstem dams were not estimated with Equation 3 because complete gate schedules were not available for those dams. However, the magnitude of water velocities through gates at various lifts for other Ohio River mainstem dams are assumed to be similar to those with estimates based on similarities in estimates among dams including Lock and Dam 7 on the Upper Mississippi River.

Equation 3 estimates the average water velocity in the plane of the gate opening and assumes a uniform flow. During submerged-orifice flow conditions when gates are in the water, the plane of highest velocity actually occurs downstream of the gate opening because of flow contraction. Based on a maximum contraction of 0.6, water velocities just downstream of the gate opening can be up to 66% higher than the velocities in the gate opening (Wilcox et al. unpublished report). As the gate opening increases, the flow-contraction factor decreases, and the magnitude of the water velocity in the gate opening approaches the maximum velocity. When the dam is at open river (i.e., gates out of the water), the plane of the gate opening is probably the plane of maximum velocity because of negligible flow contraction.

Based on a model of Lock and Dam 8 on the Upper Mississippi River (Osvalt and Grace unpublished data) water velocities through gate openings during open river are nonuniform, and lower than predicted by Equation 3 in some areas. For example, some velocity estimates in the upper portion of the gate opening based on the physical model were about 1 m/s, while values predicted by Equation 3 under the same conditions were 2.1 m/s. In contrast during submerged-orifice flow (i.e., gates in the water), the physical model generally indicated that water velocities immediately downstream of the gate openings were more uniform and nearly the same as or greater than those predicted by Equation 3. Low velocity areas and even back eddies were present 4.88 m directly downstream from the roller gate opening at relatively high lifts. However, fish would still encounter the relatively high water velocities in the gate opening when passing upstream.

The total length of the dam sill (gate sill + stilling basin) for Ohio River mainstem dams is generally in excess of 30 m (Tables 3a-3c; Figure 4). However, the portion of that distance affected by water velocities near the maximum velocity is uncertain, but important in regards to fish passage. A study by Alexander (1992) for example, found that water velocities measured about 8.5 m upstream of the tainter gate openings at Dam 24 on the Upper Mississippi River when lift was 3.6 m were only 7% of the estimated water velocities (Equation 3) in the gate opening. At low lift (i.e., 0.6 m), measured upstream water velocities were 64% of estimated velocities. Similarly, the physical model for Lock and Dam 8 on the Upper Mississippi River (Osvalt and Grace unpublished data) indicated that water velocities 4.88 m upstream of the gate centerline were substantially lower than gate opening velocities predicted by Equation 3, particularly at high lift. Directly downstream of the gate openings (i.e., 1.5 m [tainter gate] and 4.88 m [roller gate]), water velocities were generally equal to or greater than those predicted by Equation 3 during controlled and open-river conditions. These observations suggest that the entire sill is not affected by high flows and that fish moving through the dam encounter the highest velocities immediately downstream of the gate opening, with substantially lower velocities just upstream. However, the portion of the dam sill affected by water velocities near those estimated by Equation 3 could not be determined from these hydraulic studies; thus,

uncertainty remains as to the distance a fish would have to swim at relatively high water velocities to pass a dam.

Critical lift—A comparison of fish swimming speeds (Table 8) and estimated water velocities through the gate openings (Figure 8) revealed that water velocities were always even at the open river (i.e., minimum lift possible), in excess of the prolonged swimming speeds of target fishes. This indicates that target fish swimming at prolonged speeds cannot pass through the gates of Ohio River mainstem dams unless substantially lower than average water velocities are present in the gate openings because of nonuniform flow. However, if the physical model for Lock and Dam 8 on the Upper Mississippi River (Osvalt and Grace unpublished data) reflects conditions at Ohio River dams, and nonuniform flows provide areas with reduced water velocity (i.e., <1 m/s), then the prolonged swimming speeds of some target fishes may be adequate to pass through the dam during open river. Fish swimming at prolonged speeds probably could not swim through gates during controlled flow conditions because of more uniform high water velocities in excess of 2 m/s (Figure 8).

If fish can pass upstream through the gate opening within the duration of their burst swimming speed performances (i.e., 10 to 20 s before reaching exhaustion) by using areas of average velocity (i.e., Equation 3) or less (i.e., as predicted in the Upper Mississippi River model; Osvalt and Grace unpublished data), then some target species may be able to move through these dams during open river or even during low-lift conditions. However as previously noted, uncertainty remains as to the distance a fish must swim at burst speeds through high water velocities to pass the dam. Assuming that fish must pass through water velocities equal to those predicted by Equation 3 (Figure 8) for 10 m to get through the dam and that fish can maintain their burst speed for at least 10 seconds without reaching exhaustion, then a fish's burst swimming speed must exceed the water velocity by 1 m/s to pass the dam (i.e., 1 m/s * 10 s = 10 m). Thus, an estimated burst swimming speed of =3.14 m/s (i.e., 2.14 m/s + 1 m/s) would be required to pass through the dam with the minimum water velocity at open river (i.e., Greenup Dam; Figure 8). Using this same logic, a burst swimming speed of 3.68 m/s would be required by fish to swim through dams with the average minimum water velocity. Burst speeds of this magnitude were generally not observed or estimated from empirical models for target species (Table 8). However, estimated burst speed based on maximum swimming speed (U_{max}; Equation 1) for target species often exceeded 3.50 m/s (i.e., 23 of 44 target species; Table 8); this suggests that passage may be possible for some species at some dams if 10 m is a reasonable estimate of the portion of the sill affected by high water velocities.

At open river, water velocities through gate openings may be nonuniform and reduced in magnitude in some areas (Osvalt and Grace unpublished data). As well, average water velocity through the gate openings is the least at minimum head (i.e., open river; Figure 8). This suggests that fish swimming at burst or prolonged speeds should have better opportunities to pass through the dams at open river as compared to controlled conditions. Given that average water velocities at open river are already near the upper limit of burst speeds observed and estimated for target species (Figure 8; Table 8), the likelihood of passing these dams with lift greater than the minimum lift (i.e., open river) is doubtful, particularly considering flow contraction and the more uniform flow through a submerged orifice (i.e., a gate opening under controlled conditions).

This comparison of fish swimming speeds and water velocities through gate openings during open-river and controlled-flow conditions suggests that critical lift (i.e., the minimum lift that allows fish passage) is probably equivalent to open river. Fish passage through Ohio River

dams during controlled-flow conditions seems unlikely given the high magnitude of the water velocities and the uniform flow pattern. Conversely, the lower magnitude and nonuniform pattern of water velocities during open river may provide fish swimming at prolonged or burst speeds the opportunity to pass through the dam. Based on these deductions, the frequency of critical lift was assumed to be equivalent to the frequency of open river for all Ohio River mainstem dams.

Frequency of open river—The frequency of open river by week and hence the potential for fish passage varied spatially along the river by dam and temporally with discharge (Table 9). The general spatial pattern of open river suggests that the potential for fish passage is low to high at dams in the Louisville District, low to moderate at Huntington District dams, and low at Pittsburgh District dams. In general, open-river conditions were more frequent during winter and spring (i.e., high-flow period; December through June) and generally nonexistent during summer and fall (i.e., low-flow period). The open-river period generally narrowed with the distance of the dam upstream from the mouth of the Ohio River (Table 9).

In the Louisville District (i.e., Dam 52 through Markland Dam; eight dams), the two wicket dams were at open river most weeks (Table 9). During the high-flow period, Smithland Dam was at open river 15% to 45% of years by week, but generally less than 35%. The J. T. Myers and Newburgh Dams had similar patterns of open river during high-flow periods with a range of 15% to 80% of years by week for both dams. These dams had periods of 13 to 18 weeks where frequencies of open river were greater than 50% of years. The next two dams, Cannelton and McAlpine Dams, had patterns of open river during peak flow periods that were similar to Smithland Dam. The last dam in the Louisville District, Markland Dam, was rarely at open river (=15% of years by week) even during the high-flow period.

In the Huntington District, the first four dams (i.e., Meldahl, Greenup, R. C. Byrd, and Racine Dams) had open-river conditions between 0% and 50% of years by week during the high-flow period, but generally less than 30%. The remaining two dams in the District, Belleville and Willow Island Dams, had only two or three calendar weeks (i.e., weeks 8, 9, or 10) during the high-flow period when open-river frequencies were about 10% to 20% of years; otherwise frequencies were generally less than 5% of years by week.

The mean number of days a given dam was at open river during an open-river week varied by dam (Table 10), with a general decreasing trend going upstream. Recall that to be considered an open-river week in the frequency analysis, the dam had to be at open river only one day during the week. For Dams 53 through McAlpine (i.e., seven dams), the mean number of days that these dams were open during open-river weeks ranged from 3.5 to 6.8 days. For Markland through Racine Dams (i.e., five dams), the mean number of days that these dams were open per open-river week ranged from 2.3 to 3.0 days. For the remaining dams, Belleville through Emsworth Dams (i.e., eight dams), the mean number of days that these dams were open per open-river week was less than 2.0 days.

Spawning-migration periods relative to open river—Weekly average water temperature for a given calendar week varied about 2°C over the length of the Ohio River with higher temperatures in the lower reaches as compared to the upper reaches (Table 11). This low variability in temperatures across navigation pools resulted in low spatial variation in estimated spawning-migration period for a given species across pools (Appendix B). In general, the comparison of the timing of open river to fish spawning-migration periods revealed that fish that

migrate at low temperatures (e.g., walleye *Stizostedion vitreum*; Appendix B) encounter the greatest opportunity for moving through the dams because the high-flow period (i.e., open-river period) on the Ohio River occur in late winter to early spring, whereas fish spawning at warmer temperatures (e.g., channel catfish *Ictalurus punctatus*; Appendix B) tend to miss the greatest opportunities. This is even more likely the scenario at upstream dams as compared to downstream dams, because the period of open river narrows going upstream (Table 9) and migration periods for a given species do not vary much by navigation pool.

Life history, abundance, and distribution of target species—Life history characteristics relevant to fish passage, and abundance and distribution of the 44 target species by reach (upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) are summarized in Table 12. Abundance and distribution of the 44 target species by navigation pool and reach are summarized in rows two through four in the migration period tables in Appendix B. A more detailed account of life history, distribution, abundance, and fish-passage considerations for the species or groups of species identified by the ORMSS–Environmental Team (i.e., paddlefish, skipjack herring, hiodontids, ictiobids, moronids, sauger, walleye, lake sturgeon *Acipenser fulvescens*, shovelnose sturgeon *Scaphirhynchus platorynchus*, American eel, blue sucker, blue catfish *Ictalurus furcatus*, silver carp *Hypophthalmichthys molitrix*, and bighead carp *H. nobilis*) appear in the Species of Special Interest section that follows the general discussion.

General Discussion

Fish passage at open river—Circumstantial evidence suggests that fish passage upstream through the gates of mainstem dams on the Ohio River may be possible when dams are at open river. This evidence includes reports of upstream movement of fishes through these dams and through dams of similar design on the Mississippi River during open river (Holland et al. 1984; Johnson et el. 1997; Henley et al. 2001; Knights et al. 2002; Zigler et al. 2003; C. O'Bara, West Virginia Department of Natural Resources, Parkersburg, West Virginia, personal communications). As well, the comparison of fish swimming speeds and average water velocities through dam gates suggests that many fish species swimming at burst speeds may be able to pass through these dams at open river if the length of the affected sill does not exceed about 10 m. Additionally, a hydraulic study on a dam of similar design to those on the Ohio River suggested that areas of relatively low water velocity exist in the upper portion of the water column in the gate openings during open river (Osvalt and Grace unpublished data); thus, fish swimming through these areas at prolonged or burst speeds may be able to pass upstream through the dams during open river.

Fish passage over the fixed weir when the dam is at open river may be possible, but information was not available to assess the water velocities and hence the potential for passage. Likewise, fish passage through the navigable-passes at Dams 52 and 53 could not be assessed but may be possible during open river because of near natural flow dimensions when wickets are positioned horizontally. Information needed to determine the water velocities over the fixed weirs and navigable-passes include the discharge and the dimensions of water flowing over the weir. An additional pathway for fish passage may be available as the river elevation rises above bankfull during open river; the complex structure and bottom contour of the flooded landscape probably creates areas with low water velocity suitable for fish passage.

Fish passage at normal flow—Fish passage through the gate openings during normal-flow conditions seems unlikely based on the uniform nature and high magnitude of water velocities predicted by flow dimensions and discharge (Figure 8) and demonstrated with the Upper Mississippi River Lock and Dam 8 physical model (Osvalt and Grace unpublished data). In addition, submerged-orifice flow (present under controlled-flow conditions) results in water velocities greater than those predicted by Equation 3 because of flow contraction. This flow contraction results in water velocities just downstream of the gate opening up to 66% greater than those velocities estimated in the gate opening with Equation 3. Additionally, Monk et al. (1989) found that American shad avoided submerged-orifices in a full-scale model of a section of a fish ladder. The degree to which other species may avoid submerged orifices is unknown.

Fixed weirs are probably impassable by fish during normal-flow conditions because either water does not flow over them (i.e., normal pool elevation less than weir elevation; e.g., Pike Island Dam; Tables 3a-3c) or lift across the weir creates cascading flows impassable by non-jumping fishes (i.e., probably most target species). Some passage over the fixed weir may be possible as the tailwater elevation approaches the normal pool elevation (i.e., approaching open river), but again information to assess passage under these conditions was not available.

Frequency of fish-passage opportunities—Upstream fish passage at Ohio River mainstem dams with gated sections (i.e., all dams except Dashields Dam, Dam 52, and Dam 53) may be possible for many of the target fishes during open river. Passage also seems possible at Dams 52 and 53 during open river given the more natural flow dimensions present at these dams when wickets are positioned horizontally; conversely, restricted flow dimensions over the fixed weir at the Dashields Dam may result in higher water velocities not as conducive to upstream fish passage as compared to Dam 52 and 53. The frequency and duration of open river, and hence fish-passage opportunities, were not consistent among dams, generally increasing with ORKm (i.e., going downstream from the source). The first eight dams from the source, including Emsworth, Dashields, Montgomery, New Cumberland, Pike Island, Hannibal, Willow Island, and Belleville Dams, rarely attain open river and thus upstream fish passage through gates or over fixed weirs at these dams is probably rare. Generally, any fish passage at these dams probably occurs through the lock chamber. As discussed before, passage through the lock chamber during normal operations is probably not a viable (in the population sense) means of fish passage because of non-conducive flow patterns, which may confuse fish trying to move upstream.

Other dams, including Racine, R. C. Byrd, Greenup, Meldahl, McAlpine, Cannelton, Newburgh, J. T. Myers, and Smithland Dams, provide low to high opportunities for upstream fish passage based on open-river frequencies and durations. Of these nine dams, Newburgh and J. T. Myers Dams provide the greatest opportunity with the frequency of open river exceeding about 50% of years for a period of 13 and 18 weeks, respectively, during the high-flow period in winter and early spring. If fish can pass through Dams 52 and 53 during open river, these dams provide abundant opportunity nearly year-round. Conversely, Markland Dam is rarely open and thus probably presents fish with few opportunities for upstream passage.

Capabilities of fishes to pass dams—Fishes with the greatest prolonged and burst speeds and with behavioral or morphological characteristics conducive to passing through high and variable flows are probably the most capable to pass upstream though mainstem dams. For example, the

clupeids (i.e., Alabama shad, and skipjack herring), hiodontids (goldeye *Hiodon alosoides* and mooneye *Hiodon tergisus*), and larger moronids (i.e., striped bass *Morone saxatilis*, white bass *Morone chrysops*, and yellow bass *Morone mississippiensis*) had relatively high prolonged (~0.8 m/s) and maximum burst speeds (~4 m/s; Table 8) suggesting that they may be more capable of passing upstream through gates of mainstem dams than fish with lower swimming speeds. As well these species are pelagic or benthopelagic (Table 12), a characteristic that may be advantageous as compared to benthic because the areas of lowest water velocity through the dam gates may occur near the water surface with increasing water velocity toward the bottom (Osvalt and Grace unpublished data). Other relatively strong swimmers that are pelagic or benthopelagic and may be able to take advantage of lower velocities in the upper portion of the water column include paddlefish, common carp, grass carp *Ctenopharyngodon idella*, silver carp, bighead carp, carp suckers, white sucker *Catostomus commersoni*, ictiobids, moxostomids, largemouth bass *Micropterus salmoides*, sauger, walleye, and freshwater drum *Aplodinotus grunniens* (Tables 8 and 12).

Other strong swimmers that may be at a slight disadvantage because of their benthic tendencies as compared to pelagic fishes include the blue sucker, spotted sucker *Minytrema melanops*, channel catfish, and blue catfish. However, some benthic fishes are known to demonstrate sub strate appression (e.g., shovelnose sturgeon; Adams 1997). Substrate appression is the ability of a fish to hold its position on the bottom in high water velocities by flexing its pectoral and pelvic fins or body to generate a downward thrust from the passing water (Mitchell 1989). This behavior may allow benthic fish to alternate between burst swimming and resting to pass through high velocity areas, whereas pelagic fishes would have to continually swim through these areas (Mitchell 1989). Substrate appression may be enhanced by morphological features such as a flattened head, for example as seen with shovelnose sturgeon, blue catfish, and channel catfish.

Fishes with elongated bodies (sturgeon and northern pike) have generally lower estimated swimming speeds as compared to other fishes, thus potentially making these elongated forms less capable of passing upstream through the gates of mainstem dams. Additionally, sturgeon and gar may be at a disadvantage to scaled fishes because they have hardened scutes. Webb (1986) calculated that the drag per unit area for lake sturgeon is 3.5 times that of a similar size trout; he suggested that this was probably because of a "pressure drag penalty" for having scutes. Despite this apparent increased drag lake sturgeon are known to move upstream through mainstem dams in the Upper Mississippi River during open river (Knights et al. 2002). Further research on the swimming capabilities, behaviors, and morphological features of fishes relative to passing through areas with high and variable water velocities, such as those found in the gate bays of Ohio River mainstem dams, is needed to reduce the uncertainty in assessing fish passage by target fishes.

Abundance and distribution of target species relative to fish passage—Synthesis of the abundance and distribution information (Table 12; Appendix B) and the frequency of fish-passage opportunities at mainstem dams (Table 9 and Appendix B) suggest that at least half of the target species do not need to move upstream through mainstem dams to persist in the Ohio River across broad reaches. This includes species that are generally common in all three reaches (i.e., longnose gar, mooneye, skipjack herring, common carp, river carpsucker *Carpiodes carpio*, quillback *Carpiodes cyprinus*, smallmouth buffalo *Ictiobus bubalus*, channel catfish, white bass, largemouth bass, sauger, walleye, and freshwater drum). As well, species that are generally

common in the middle or upper reach but not in the lower reach (i.e., spotted sucker, silver redhorse, river redhorse *Moxostoma carinatum*, black redhorse *Moxostoma duquesnei*, golden redhorse *Moxostoma erythrurum*, shorthead redhorse *Moxostoma macrolepidotum*, and smallmouth bass *Micropterus dolomieu*) may not be dependent on passage to persist. The common status of these fishes in the upper- or middle-reach pools, where opportunities for fish passage are rare, suggests that local populations or upstream populations are providing recruitment in these navigation pools. The absence or low abundance of some of these species in the lower reaches may just suggest that habitat or environmental conditions are not suitable for these species, rather than any limitation imposed by fish passage.

Most of the Ohio River target fishes are known to migrate (Table 12). Many of these migrations are upstream to spawning areas in flowing water (e.g., many of the fluvial-dependent and fluvial-specialist species; Table 12), presumably followed by dispersal back downstream to resting and feeding areas. Even though many species of Ohio River fishes are reported to make upstream migrations, the importance of inter-pool migrations, in terms of maintaining abundance and distribution, is difficult to assess and probably variable among species. For example, all of the life history requirements of a species may be adequately met within a given pool; suitable substrates and conditions for adults to spawn may be present, and eggs and larvae may find or drift to suitable areas within a pool. As well, adequate feeding, resting, and wintering areas may be available within the pool. Alternatively, the presence of a species in a particular navigation pool may be sustained because populations in upstream pools or tributaries are the sole or at least a supplemental source of recruitment for the downstream pool, thus negating the need for this species to pass upstream through dams.

Conversely, navigation dams may be limiting the abundance and distribution of species that are generally only found in the lower reach or have been extirpated from the system (i.e., lake sturgeon, shovelnose sturgeon, shortnose gar, Alabama shad, bighead carp, blue sucker, bigmouth buffalo *Ictiobus cyprinellus*, blue catfish, and yellow bass; Table 12). Likewise, the distribution of species found in the lower and middle reaches but not generally in the upper reach (i.e., paddlefish, goldeye, American eel, grass carp, silver carp, highfin carpsucker *Carpiodes velifer*, white catfish *Ameiurus catus*, and striped bass; Table 12) suggests that dams may limit these species. This deduction is substantiated by the generally broader distribution and greater abundance of at least some of these species before the construction of mainstem dams (e.g., most obviously, lake sturgeon, shovelnose sturgeon, paddlefish, American eel, blue sucker; see Species of Special Interest section).

For species that are known to make long-distance migrations (e.g., anadromous species, paddlefish, and lake sturgeon; Table 12), movements upstream through dams may be particularly important because their evolutionary history may require very specific conditions, not met within a single pool, to ensure successful mating, and survival of the young. As well, paddlefish and lake sturgeon are known to range broadly, yet at times home to wintering, feeding, and spawning habitats (Auer 1996; Jennings and Zigler 2000; Knights et al. 2002; Zigler et al. 2003). The combination of these characteristics (nomadic and homing) probably makes upstream movement through dams a prerequisite to viable populations. As well, Auer (1996) suggested that egg maturation may occur during the migration of lake sturgeon, thus alterations in the distance, and hence duration, of migrations resulting from dams may negatively affect reproductive success.

However, even when evidence suggests that the abundance and distribution are reduced (e.g., shovelnose sturgeon, paddlefish, American eel, and blue sucker) or that species have been extirpated (e.g., lake sturgeon and Alabama shad), it is difficult to establish that lack of fish

passage is the cause of these losses because other historical, concomitant stressors, such as habitat changes, introduction of exotics, overharvest, and degraded water quality, may play a role in population declines (Pearson and Krumholz 1984). Many target species, particularly those that are widely distributed, are considered tolerant of pollution (Table 12), potentially suggesting the entire system is degraded or that sensitive species have not recovered from previous assaults. Pearson (1992), along with numerous others, have noted that some fishes are only recently showing signs of expanded ranges into the upper 160 km of the Ohio River (mid-Hannibal through Emsworth Pool) following severe pollution before 1970. As well, species that have been extirpated from one system with dams may still be present in other systems with dams (e.g., lake sturgeon in the Upper Mississippi River System but not in the Ohio River System and skipjack herring in the Ohio River System but not the Upper Mississippi River System; see Species of Special Interest section), again leaving uncertainty as to the role of dams.

Much uncertainty as to the effects of dams on fishes inhabiting large river systems will remain despite the efforts of researchers and managers to elucidate the issue. These uncertainties will remain because past and present stressors on large river systems have acted or act concurrently with dams to affect fish populations. As well, population assessments at the level of detail necessary to elucidate changes in abundance and distribution were not conducted particularly before dams in the Ohio River and thus any comparisons between pre- to post-dam periods become qualitative. Finally, system-specific research on the life history characteristics of Ohio River fishes is lacking, thus making assessments of the importance of longitudinal movements by these fishes difficult.

Despite uncertainties, recent literature on the ecological structure and function of large rivers indicates that longitudinal connectivity is important to river biota in many respects, and particularly so for fishes. Large river fish populations evolved under conditions that were less restrictive in terms of longitudinal movement as compared to present conditions. Thus, restrictions imposed by mainstem dams probably affect the distribution, abundance, and productivity of these populations by imposing limitations on life cycle completion and metapopulation dynamics. Our analyses of critical lift and frequency of open river suggest that fishes in the Ohio River are now probably more restricted longitudinally as compared to pre-dam conditions. The information on abundance and distribution for some species, particularly those that are highly migratory (e.g., Alabama shad, lake sturgeon, paddlefish, American eel), lend credence to the assertion that restricted longitudinal movement negatively impacts these fishes.

Dams on large rivers may negatively impact metapopulations of native fishes by reducing available habitat and immigration between subpopulations, thus making them less resilient to disturbances and more vulnerable to extinction. Francis (2003) surmised that coho salmon *Oncorhynchus kisutch* populations in Oregon are less productive and less resilient than historically because anthropogenic factors, like dams, have reduced life history variability necessary in an inconsistent and unpredictable environment. Restricted fish passage at mainstem dams has probably had similar effects on populations of anadromous and potadromous fishes in the Ohio River, but because of the qualitative nature or lack of information on abundance and distribution and because of concurrent stressors, these effects are difficult to verify.

Recommendations

The Ohio River System has been significantly modified by dams resulting in drastically altered physicochemical properties and disruption of longitudinal connectivity. Ecological principles

concerning metapopulation dynamics suggest that the biodiversity and bioproduction of native fishes in large rivers will be negatively affected by the reduced immigration and loss of habitat associated with dams (Stanford et al. 1996; Hanski 1998); after decades with dams, these consequences seem evident in the fish fauna of the Ohio River. As well, the inability of some species to complete their life cycle because required habitats are separated by generally impassable dams has undoubtedly affected abundance and distribution of these fishes in the Ohio River. These negative effects of dams mandate that restoration and enhancement efforts for fishes in the Ohio River include fish passage in conjunction with habitat restoration to be fully successful. Although most fish species present now will probably persist and some will possibly increase under present conditions, others will probably decline and possibly become extirpated if broader restoration efforts that include fish passage are not undertaken. At a minimum, most species will not reach their bioproduction potential without consideration of fish passage. As well, reintroductions of extirpated fishes that were probably most impacted by the loss of longitudinal connectivity given their life histories will be limited without addressing passage and habitat connectivity issues.

A myriad of issues surround the implementation of fish-passage improvements at mainstem dams on the Ohio River including target species, operational versus structural passage measures, cost-benefit, funding, invasive species, and the effects on other waterway users (i.e., municipal, commercial, and recreational). A thorough analysis of these issues has been completed on the Upper Mississippi River as part of the Navigation Study (D. Wilcox, U.S. Army Corps of Engineers, St. Paul, Minnesota, personal communications) and will undoubtedly benefit any future efforts by managers on the Ohio River. Issues concerning target species include which species, habitat requirements and connectivity, importance of tributaries, prioritization of dams, operational or structural measures, and type of structures. Obviously, target species should include those migratory species that have apparently been most affected by the disruption of longitudinal connectivity including Alabama shad, lake sturgeon, American eel, and paddlefish. However many other species, including small-bodied forms not covered in this report will probably benefit from connectivity of subpopulations under the principles of metapopulation dynamics (Hanski 1998; Jungwirth 1998) and should be considered in efforts to improve fish passage at mainstem dams.

Operational as well as structural measures to improve fish passage at mainstem dams on the Ohio River should be considered. For example, increasing the frequency and duration of open river by altering operational procedures used by dam operators to control water levels, or operating the locks in such a manner as to pass fish when not being used for navigation should be investigated. While less expensive than structural measures, operational measures are generally untested and may provide only limited improvements.

In the Upper Mississippi River, nature-like (i.e., rock-ramp) fishways are being seriously considered to improve fish passage at mainstem dams because of their applicability to a wide array of fish species, fish sizes, and hydrologic conditions (Gebler et al. 1998; Harris 1998). Although more conventional passage structures (e.g., vertical slot and Denil) have been designed primarily to pass adult salmonid species (Schwalme and Mackay 1985) and can be relatively expensive, they should be included in assessments of alternatives in the Ohio River because they can pass non-salmonid species (Schwalme and Mackay 1985; Bunt et al. 1999, 2001) and may be more applicable to high-lift dams or where space is limiting (Gebler 1998; Parasiewicz et al. 1998) as compared to nature-like fishways. Although similar in basic design (i.e., gated, fixed-weir, and lock sections) to Mississippi River mainstem dams, the dams on the Ohio River

tend to have greater lift that will probably make implementation of operational and structural measures more challenging and costly.

Finally, any assessment of restoration efforts will have to include a cost-benefit analysis and a determination of how to best spend limited monies for restoration. As stated previously, operational measures may be less expensive but at the same time are unproven and possibly less effective than structural measures. With limited dollars available, habitat restoration within pools and associated tributaries to accommodate the full array of life history requirements for some species may be the only affordable alternative albeit limited. Preliminary estimates for nature-like fishways at mainstem dams on the Upper Mississippi River are in the tens of millions of dollars; probably a high proportion of what is typically available for restoration. As well, assessing the effectiveness of fishways and putting a dollar value on the benefits of improved fish passage will be fraught with difficulties because of the nature of the perceived benefit (i.e., bioproduction and biodiversity of native fishes).

However, there is a growing recognition that efforts will need to go beyond species- and site-specific management to restore the natural bioproductivity and biodiversity of large regulated rivers (Stanford et al. 1996). River systems are large complex ecosystems necessitating restoration efforts at comparable scales and complexities followed by long-term assessment and adaptive management. To be successful, these efforts will need to focus on systemic issues including the restoration of more natural flow regimes, floodplain connectivity, water and substrate quality, and fish passage.

Species of Special Interest

The ORMSS-Environmental team identified some species or groups of species that were of particular concern based on abundance and distribution, as well as on ecological and economic considerations. These included widely distributed species or groups including paddlefish, skipjack herring, hiodontids, ictiobids, moronids, sauger, and walleye; species with restricted distribution including lake sturgeon, shovelnose sturgeon, American eel, blue sucker, and blue catfish; and several nonnative (potentially nuisance) species including silver carp and bighead carp. The life history characteristics, swimming abilities, abundance and distribution information, and fish-passage issues for these species or groups are discussed in the sections that follow (in phylogenetic order).

Lake sturgeon are considered a benthic large-river species that are fluvial dependent, generally requiring flowing water for reproduction. They are nonguarder litho-pelagophils (i.e., spawn over rock or gravel, larvae drift after hatching), and spawning takes place in the spring at water temperatures of 8 to 21°C (14 to15 C° seems optimal) in areas with water velocities of 0.1 to 0.15 m/s (Wallus et al. 1990; Jennings 1991). Spawning occurs in areas of swift water or rapids, outside bends of riverbanks where current is upwelling, at low falls, or near dams that preclude upstream movement (Wallus et al. 1990; Fortin et al. 1993; Bruch 1999). Eggs are demersal and attach to the substrate. Larvae hatch and drift downstream, presumably to nursery areas. Males reach sexual maturity at an age 8 to 22 years and at total lengths of 752 to 1,270 mm; females mature at age 12 to 33 years and at total lengths of 800 to 1,400 mm (Lee et al. 1980; Wallus et al. 1990; Jennings 1991). The majority of males are thought to spawn at least every other year and females every 4 to 7 years (Wallus et al. 1990; Lyons and Kempinger 1992).

Lake sturgeon are known to migrate long distances between spawning, feeding, and wintering areas (Wallus et al. 1990; Fortin et al. 1993; Auer 1996; Rusak and Mosindy 1997; Bruch 1999; Knights et al. 2002). Often times these migrations are from rivers or lakes into tributary streams. Wallus et al. (1990) cited one tagging study where lake sturgeon migrated up to 400 km and males returned to the same spawning location in subsequent years. In his review on lake sturgeon, Jennings (1991) suggested that lake sturgeon may home to natal spawning sites. Knights et al. (2002) reported median maximum extent of movement from tagging sites of adult-sized lake sturgeon from two groups in the Upper Mississippi River to be 56 and 97 km. They noted extensive movements of lake sturgeon during spring, summer, and fall between a core area in the mainstem of the Mississippi River and a large tributary, and between another core area in the mainstem and other mainstem reaches. These movements suggested a homing behavior to core feeding and wintering sites. During this 18-month study, lake sturgeon moved upstream (10 fish, 19 passages) and downstream (13 fish, 35 passages) through navigation dams on the Upper Mississippi River a total of 54 times (Knights et al. 2002). Most upstream passage events occurred during open river or during a period that included open-river and controlled-flow conditions, thus leaving uncertainty as to what conditions actually existed at the time of passage, but suggesting upstream passage during open river. Wallus et al. (1990) suggested that nonspawning movements in spring, summer, and fall were associated with selection of favorable water temperatures by lake sturgeon. Knights et al. (2002) and Bruch (1999) suggested that some movements by lake sturgeon from feeding areas in the summer or fall to tributaries may be associated with spawning that will occur the following spring.

Prolonged (U_{crit10}) and burst (10 s duration) swimming speeds of adult-sized (101 cm median total length) lake sturgeon were estimated as 0.82 and 1.55 m/s, respectively (Peake et al. 1997). The prolonged speed for lake sturgeon is near the upper end of those reported for target species. However, burst swimming speed is relatively low given the median size of adult lake sturgeon. Webb (1986) calculated that the drag per unit of wetted surface area for lake sturgeon is 3.5 times that of a similar size trout; he suggested that this was probably because of a "pressure drag penalty" for having hardened scutes rather than scales. The U_{max} estimates derived with the methods of Winter and Van Densen (2001) were 2.4 and 2.86 m/s, but may also overestimate maximum speed because of the added drag associated with scutes.

The lower Ohio River System is at the southern extent of the native range of lake sturgeon (Lee et al. 1980). Pearson and Krumholz (1984) stated that lake sturgeon were once abundant throughout the Ohio River, generally citing Trautman (1981) as the source of this information. In a later review of literature and data, Pearson and Pearson (1989) noted that lake sturgeon had been reported in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) between 1800 and 1969, but that no recent (post-1969) reliable records exist (Appendix B). Pearson and Krumholz (1984) suggest that the validity of a recent report from the middle reach (ORKm 785 in the Markland Pool in 1971) by Trautman (1981) should be doubted. Pearson and Pearson (1989) indicated that the lake sturgeon should be considered extirpated from the Ohio River and implicated navigation dams as a probable reason for their absence.

Trautman (1981) cites several sources that lake sturgeon were present, and even abundant in some instances, in the Ohio River as far east as western Pennsylvania in the 1800s and early 1900s. Trautman (1981) also cites early sources (i.e., pre-impoundment) that noted the occurrence of lake sturgeon in the Muskingum River, which enters the present day Belleville Pool just below Willow Island Dam (i.e., upper reach), and in the Scioto River, which enters the

present day Meldahl Pool just below Greenup Dam (i.e., upper margin of middle reach). The report of lake sturgeon in the Scioto River noted that they commonly migrated as far upstream as Circleville and that "stragglers" were as far upstream as Columbus, Ohio, and in several small tributaries of the Scioto River. Trautman (1981) stated that after 1916 (post-impoundment), the numbers of lake sturgeon in the Ohio River declined sharply. He goes on to suggest that the decline of lake sturgeon in Ohio waters, presumably including the Ohio River, appeared to have been caused by dams that block spawning migrations; destruction of spawning habitat by siltation, pollution, and drainage; and destruction of mollusk food resources.

In a species account, Wallus et al. (1990) cited Burr and Warren (1986) indicating that lake sturgeon were formerly present in the Ohio, Tennessee, and Cumberland Rivers of Kentucky. As well, Wallus et al. (1990) cited Eagar and Hatcher (1980) that lake sturgeon were formerly widespread in large rivers of Tennessee, with three confirmed recent reports (i.e., 1960s or 1970s) from the Cumberland and Tennessee Rivers. Smith (1979) noted that a commercial fisherman from Darwin, Illinois, reportedly captured a lake sturgeon in the Wabash River, but the date of capture was not given. Lake sturgeon were not collected in night electrofishing and lock rotenone sampling conducted between 1989 and 2001 (ORSANCO unpublished data; OEPA unpublished data); however, lake sturgeon may not be susceptible to these capture methods or may be too rare to be detected.

Whether lack of fish passage at mainstem dams is the cause of the apparent extirpation of lake sturgeon in the Ohio River System is uncertain. More likely a combination of factors, for example, overharvest, poor water quality, siltation, and blockage of spawning migration routes by dams, are to blame (Trautman 1981; Pearson and Krumholz 1984; Pearson and Pearson 1989). Several life history characteristics of lake sturgeon, including that they are benthic, highly migratory, exhibit site fidelity to spawning and feeding areas, generally spawn in flowing water over rock substrates, and produce larvae that drift downstream to nursery areas, suggest that lake sturgeon may be negatively affected by lack of upstream passage opportunities at mainstem dams.

The benthic nature of adult lake sturgeon suggests that they may be less capable of moving through open dams because they would be unable to take advantage of the lowest current velocities in the upper portion of the gate openings. However, if lake sturgeon are capable of substrate appression, as observed in shovelnose sturgeon (Adams et al. 1997), then their benthic nature may be an advantage. Knights et al. (2002) found that radio-tagged lake sturgeon moved upstream through navigation dams in the Upper Mississippi River and in most instances, these movements probably occurred during open river. Given the similarities in estimated water velocities through gate openings between Mississippi and Ohio River mainstem dams during open river (Figure 8), and the evidence of upstream passage at Ohio River dams by other fish species, it is likely that lake sturgeon could pass upstream through Ohio River dams during open river.

The literature suggests that lake sturgeon move long distances during spring, summer, and fall and that these movements are associated with spawning, feeding, or overwintering requirements (Fortin et al. 1993; Auer 1996; Rusak and Mosindy 1997; Bruch 1999; Knights et al. 2002). Auer (1996) went as far as to suggest that 250 to 300 km of barrier-free habitat be considered as a minimum for supporting self-sustaining lake sturgeon populations. Our analysis of critical lift and frequency of open river at Ohio River dams suggests that mainstem dams would impede the long distance upstream movements commonly noted for lake sturgeon. Ohio River mainstem dams that open most frequently (i.e., Louisville District dams;

Table 9) may not impede lake sturgeon during spring migrations. However, if lake sturgeon are dependent on summer or fall upstream movements for reproduction, feeding, or overwinter survival, then lower reach dams would probably be a limiting factor because they infrequently open during these periods. In general, upper and middle reach dams (i.e., Huntington and Pittsburgh District dams) open even less frequently than lower reach dams (Table 9), and thus probably act as an even greater impediment to upstream movements by lake sturgeon.

One factor that may have contributed to the extirpation of lake sturgeon and other species from the upper reach of the Ohio River was the notoriously poor water quality that occurred in that reach and its tributaries until about 1970 (Pearson 1992). Other pollution sensitive species (e.g., blue sucker, highfin carpsucker, and mooneye) apparently persisted in the lower reaches of the Ohio River during this period; these populations expanded their range back into the upper reaches after the water quality improved (Pearson 1992). Conversely, the lower reach of the Ohio River may not have been a suitable long-term refuge from poor water quality for lake sturgeon populations because the lower reach may lack suitable hard substrates necessary for successful lake sturgeon spawning. As well, the lower reach of the Ohio River defines the southern fringe of the lake sturgeon's native range (Lee et al. 1980); this suggests that habitat or physicochemical conditions (e.g., summer water temperatures) may be marginal for lake sturgeon in this reach. Alternatively, other factors (e.g., overharvest) may have contributed to the extirpation of lake sturgeon systemwide, thus re-establishment from remnant populations in the Ohio River was not possible despite improvements in water quality conditions.

The persistence of lake sturgeon in the Upper Mississippi River System, which like the Ohio River has a series of mainstem navigation dams and numerous dams on its tributaries, suggests the potential for successful reintroduction of lake sturgeon into the Ohio River. However, upstream passage opportunities (i.e., open-river conditions) are generally more frequent at dams in the reach where lake sturgeon still occur in the Upper Mississippi River as compared to the middle and upper reach dams on the Ohio River (Wilcox et al. unpublished report; Table 9). Even in the Upper Mississippi River, managers suspect that the lack of upstream fish passage is a limitation to the remnant populations of lake sturgeon. As noted previously, the potential lack of suitable spawning substrate in the lower reach of the Ohio River and the marginal habitat conditions in the lower reach as reflected by the lake sturgeon's native range argues for reintroduction into the middle and upper reaches rather than the lower reach. Thus, any reintroduction plan for lake sturgeon in the Ohio River would need to consider upstream fish-passage issues because of the lake sturgeons migratory nature and life stage-specific habitat requirements.

Shovelnose sturgeon are a benthic, fluvial specialists requiring flowing water to meet all of their life history requisites including reproduction and feeding (Keenlyne 1997; Galat and Zweimüller 2001). They are considered to be characteristic of large rivers (Pflieger 1971 in Simon and Emery 1995) and often congregate below dams or at the mouth of tributaries (Keenlyne 1997). Trautman (1981) noted that shovelnose sturgeon feed over clean sand and gravel bottoms in current. They are thought to be nonguarder litho-pelagophils (Wallus et al. 1990) that spawn from April to early July at water temperatures of 15.5 to 21.5°C, possibly cued by increased stream-flow (Forbes and Richardson 1920; Pflieger 1975; Becker 1983; Wallus et al. 1990). Shovelnose sturgeon are known to move upriver to spawn in tailwaters, at rock structures, or in tributaries (Keenlyne 1997). Males reach sexual maturity at age 5 and at a median total length of 551 mm; females reach maturity at age 7 and at a median total length of 645 mm (Forbes and

Richardson 1920; Becker 1993; Wallus et al. 1990). Most (65% to 70%) mature males are thought to spawn in a given year, while females may spawn only every 2 to 3 years (Wallus et al. 1990).

Hurley et al. (1987) noted that most movement by radio-tagged shovelnose sturgeon between April and September in Pool 13 of the Upper Mississippi River occurred during May and July, with the least movements in April and June. They noted movements of up to 17 km between activity centers, with "homing" by 8 of 22 radio-tagged fish to these activity centers. Aside from movements between activity centers, radio-tagged shovelnose sturgeon were largely sedentary during the study (Hurley et al. 1987). Additionally, Hurley et al. (1987) and Curtis et al. (1997) found that shovelnose sturgeon in the Upper Mississippi River generally used the upstream portion of navigation pools (i.e., riverine portion) rather than the downstream, impounded areas. Curtis et al. (1997) reported that 15% of locations of radio-tagged shovelnose sturgeon occurred in the tailwaters of Dam 12. Hurley et al. (1987) noted that of 146 tag returns from 2,385 tagged shovelnose sturgeon, one fish moved upstream 43 km passing through one navigation dam, and four fish moved downstream 182 to 190 km passing through four navigation dams; the other 141 recaptures occurred in the navigation pool where fish were originally tagged. Moos (1978 in Wallus et al. 1990; Keenlyne 1997) found that shovelnose sturgeon moved as far as 540 km downstream in the Missouri River and suggested that dams in the upper Missouri River may block migrations of shovelnose sturgeon to traditional spawning grounds.

Estimates of prolonged swimming speeds (U_{crit}) based on work by Adams et al. (1997) and Tunink (1975) range from 0.65 to 0.77 m/s for adult fish. The estimated burst speed of a median adult-sized shovelnose sturgeon based on a lake sturgeon model (Peake et al. 1997) was 1.00 m/s. An estimate of U_{max} derived with the methods of Winter and Van Densen (2001) was 3.00 m/s, but like those for lake sturgeon may be an overestimate of burst speed because of increased drag associated with the fish's scutes (Webb 1986). Shovelnose sturgeon exhibit substrate appression, a behavior that allows them to hold their position on the bottom in high water velocities (Adams et al. 1997); this behavior may enable shovelnose sturgeon to move upstream through mainstem dams if their estimated burst speeds are near 3.00 m/s as predicted by U_{max}, as opposed to 1.00 m/s as predicted by the lake sturgeon model.

The Ohio River defines the eastern limit of distribution for shovelnose sturgeon (Lee et al. 1980). Pearson and Pearson (1989) found that shovelnose sturgeon were present in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle— ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) in an early period (1800 to 1969), and only in the lower two reaches in a recent period (post-1969; Appendix B). Pearson and Krumholz (1984) noted that shovelnose sturgeon populations declined dramatically in numbers between 1900 and 1950. Additionally, they noted only two reports of shovelnose sturgeon in the late 1950s from ORKm 510 to 1,194 (i.e., middle reach; Belleville to Newburgh Pool) and one report of 84 specimens taken between ORKm 1,194 to 1,578 (lower reach; Newburgh Pool to the mouth). Pearson and Krumholz (1984) noted five reports after 1970 of specimens taken between Newburgh Pool and the mouth with the most recent two reports occurring in 1981. Additionally, they noted that William Pearson collected two adult shovelnose sturgeon in the Cannelton Pool at the Falls of Ohio (i.e., lower margin of the middle reach) in 1983. Pearson and Krumholz (1984) suggest that the remnant populations of shovelnose sturgeon in the lower Ohio River are seriously threatened.

Trautman (1981) indicated that shovelnose sturgeon were common in the Ohio River during 1925 to 1950 from the mouth of the Scioto River (enters upper Meldahl Pool; upper

margin of the middle reach) westward. He also noted that according to fishermen, a marked decrease in shovelnose sturgeon abundance had occurred since about 1950 and that work done at the University of Louisville supports this supposition. Bailey and Cross (1954 in Wallus et al. 1990) noted that shovelnose sturgeon were common in the Ohio River in Washington County in eastern Ohio (i.e., the middle portion of the upper reach) until impoundment in 1911, but were rare upstream of Scioto County, Ohio (i.e., upper margin of the middle reach), after the 1950s. Burr and Warren (1986 in Wallus et al. 1990) indicated that shovelnose sturgeon were formerly common in tributaries to the Ohio River in Kentucky including the Licking (enters Markland Pool; middle reach) and Big Sandy (enters Greenup Pool; lower margin of the upper reach) Rivers. They also indicated that shovelnose sturgeon might still be present in the Tennessee, Cumberland, Green, Kentucky, and Licking Rivers (lower and middle reaches). Burr and Warren (1986 in Wallus et al. 1990) also noted that shovelnose sturgeon are occasional to common in the lower Ohio River. Smith (1979) reported that shovelnose sturgeon are more abundant in the Wabash River (enters Smithland Pool; lower reach) than in other rivers in Illinois, but that information was not available to assess their abundance in the lower Ohio River.

Our review of recent data found shovelnose sturgeon to be occasionally to commonly collected in gill nets in the lower-reach tailwaters (i.e., Newburgh Dam tailwaters and below) during the 1980s (Kinman et al. 1989). In an analysis of other recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that no shovelnose sturgeon were collected (Appendix B); however, these surveys did not include typical shovelnose sturgeon habitat (i.e., main channel and tailwater areas with moderate current).

This information suggests a reduction in the distribution or abundance of shovelnose sturgeon in all reaches of the Ohio River, particularly in the middle and upper reaches. This pattern of abundance and distribution suggests that lack of upstream passage at mainstem dams, that open more frequently in the lower reach as compared to the middle and upper reaches (Table 9), may negatively affect shovelnose sturgeon populations. As well, shovelnose sturgeon are known to migrate upstream to spawn suggesting that dams may block migrations to spawning habitats in upstream reaches and tributaries of the Ohio River. However, shovelnose sturgeon are not generally known for long-distance spawning migrations like those of lake sturgeon and may be more sedentary at other times (Hurley et al. 1987). Furthermore, shovelnose sturgeon may successfully spawn in tailwaters of dams (Keenlyne 1997), thus negating the need to move upstream through dams for successful reproduction. Conversely, shovelnose sturgeon larvae are thought to drift downstream to nursery areas; this downstream movement of larvae may necessitate movement back upstream (possibly through dams) by juvenile or adult fish to sustain fish numbers in the upper reaches. The spawning period for shovelnose sturgeon generally occurs after the peak open-river period at dams (Appendix B), particularly in the Huntington District (i.e., middle reach), suggesting that shovelnose sturgeon may have little opportunity for upstream passage during spawning migrations. Likewise, the Pittsburgh District (i.e., upper reach) dams are only rarely open (Appendix B) and thus upstream passage through those dams is probably minimal during all seasons.

Despite a report that indicated that shovelnose sturgeon can move upstream through navigation dams on the Upper Mississippi River (one fish; Hurley et al. 1987), they may not be capable of moving through the gate openings given their relatively low swimming speeds (Table 8). Shovelnose sturgeon would probably have to use substrate appression (Adams et al. 1997) in conjunction with burst swimming close to their estimated U_{max} (i.e., 3.00 m/s; Table 8) to move upstream through the relatively high water velocities in the gate openings of mainstem

dams (Figure 8). However as noted previously, U_{max} may overestimate burst swimming speeds of shovelnose sturgeon because of increased drag associated with scutes (Webb 1986). In general, the studies of shovelnose sturgeon in the Upper Mississippi River (i.e., Hurley et al. 1987; Curtis et al. 1997) indicated that upstream movement through mainstem dams is rare. This supports the hypothesis that movement through gate openings may not be possible for shovelnose sturgeon even during open-river conditions and that another pathway (e.g., through the lock chamber) may have been used in the single instance reported. Conversely, the rare occurrence of upstream passage could suggest that shovelnose sturgeon do not have the propensity to move upstream through dams. As noted previously, radio-tagged shovelnose sturgeon in the Upper Mississippi River predominately moved short distances between activity centers and were otherwise rather sedentary (Hurley et al. 1987).

Although the pattern of abundance and distribution suggests that lack of fish passage may negatively affect shovelnose sturgeon populations in the Ohio River, Pearson and Krumholz (1984) suggest that an environmental change in the Ohio River, rather than harvest or dams (i.e., lack of fish passage), is responsible for the decline of shovelnose sturgeon. In support of this hypothesis, they noted that shovelnose sturgeon were not an important commercial species nor do they undergo extensive spawning migrations. Pearson and Krumholz (1984) suggested that siltation might have reduced available food resources and spawning substrates for shovelnose sturgeon. As well, shovelnose sturgeon are fluvial specialists (Keenlyne1997; Galat and Zweimüller 2001) indicating that they may be severely affected by the conversion of riverine (i.e., lotic) habitats to impoundments (Van Hassel et al. 1988). This is supported by work done on the Upper Mississippi River that found shovelnose sturgeon generally use the upper, riverine portion of the navigation pools rather than the downstream impounded portion (Hurley et al. 1987; Curtis et al. 1997).

Paddlefish are a pelagic, fluvial-dependent species requiring flowing water for reproduction (Balon 1975; Galat and Zweimüller 2001). They are considered to be characteristic of large rivers (Pflieger 1971 in Simon and Emery 1995) and are known to congregate below dams or in other deep areas with slow-moving water (Jennings 1991; Johnson et al. 1997; Henley et al. 2001; Zigler et al. 2003). Paddlefish move upstream to spawn in the spring when water temperatures are about 10 to 16°C and may be cued to spawn by rising water levels (Wallus et al. 1990; Jennings 1991). They are nonguarder litho-pelagophils that spawn over gravel-rubble substrate in water 2 to12 m deep (Wallus et al. 1990). Paddlefish eggs are demersal and larvae drift downstream to nursery areas (Wallus et al. 1990). Males are sexually mature at age 6 to 9 and at total lengths of 1,020 mm to 1,397 mm; females are sexually mature at age 7 to 12 and at total lengths of 1,070 mm to 1,397 mm (Wallus et al. 1990; Jennings 1991).

Paddlefish are known to be highly migratory within large river systems. Smith (1979) indicated that paddlefish move up tributaries to dams that block their migration. Henley et al. (2001) noted that extensive movements are characteristics of all ages of paddlefish and suggested that upriver movement through mainstem dams on the Ohio River may be restricted even at open river. Conversely, documentation of upstream passage through navigation dams was more common than downstream passage for paddlefish tagged as part of a basin-wide (i.e., Mississippi River Basin including the Ohio River) mark-recapture effort (Conover and Grady 2000; Henley et al. 2001). Johnson et al. (1997) found that paddlefish radio-tagged at the mouth of the Scioto River in Meldahl Pool (i.e., upper margin of the middle reach) commonly made extensive downstream and upstream movements (up to 100 km). Eight of 15 radio-tagged paddlefish

moved downstream through the Meldahl Dam, and four of these eight fish eventually moved back upstream through that dam during open river. Johnson et al. (1997) also noted paddlefish movements into several tributaries including the Scioto (up to 30 km), Brush, and Goose Laughery; all of these tributaries enter the Meldahl Pool. Others have noted movements of paddlefish through navigation dams and into large tributaries on the Upper Mississippi River (Southhall and Hubert 1984; Moen et al. 1992; Zigler et al. 2003). Zigler et al. (2003) noted that the extent of movement by radio-tagged paddlefish was up to 420 km, with numerous fish moving in excess of 100 km from tagging sites. As well, they noted 53 instances of paddlefish passing through navigation dams on the Upper Mississippi River during a 3-year study, including 20 instances in the upstream direction and 33 in the downstream direction. Upstream movement through mainstem dams on the Upper Mississippi River by paddlefish was related to lift, with a 7-fold decrease in the likelihood of upstream passage with each 1 m increase in lift (Zigler et al. in press).

Prolonged swimming speeds (U_{crit10}) for paddlefish 37 to 65 cm in length (eye to base of caudal fin) were 54.7 to 65.4 cm/s (Tunink 1975). We used 65 cm/s as an estimate for prolonged speed for adult paddlefish of median size (84 cm eye-to-fork for males); however, this may be low given that the test individuals in Tunink's (1975) work were not of median adult size. An estimate of burst speed for paddlefish based on a lake sturgeon model (Peake et al. 1997) was 1.4 m/s; this however may be low because paddlefish do not have scutes like lake sturgeon, and as noted by Webb (1986) scutes increase drag significantly. Estimates of U_{max} as a proxy for burst speeds were 2.29 and 3.0 m/s at 11 and 15°C, respectively.

As with shovelnose sturgeon and lake sturgeon, the upper Ohio River defines the eastern native range of paddlefish (Lee et al. 1980). Pearson and Pearson (1989) found that paddlefish were present in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) in an early (1800 to 1969) and recent period (post-1969; Appendix B). Pearson and Krumholz (1984) noted that paddlefish were originally found from the mouth of the Ohio River (ORKm 1,578) to ORKm 153 (in Hannibal Pool; no source given) and that they had not been reported above ORKm 690 (in Meldahl Pool) since 1970. Conversely, Trautman (1981) noted a newspaper article citing an observation of a dead paddlefish in shallow water in a small tributary of the Muskingum River (enters the upper Ohio River at ORKm 276) in 1977. In a more recent review, Pearson and Pearson (1989) indicated an upstream range extension for paddlefish since 1970 to ORKm 549 (presumably Greenup Dam lock chamber); this is supported by Johnson et al. (1997), who recorded locations of radio-tagged paddlefish in the tailwaters of Greenup Dam.

Trautman (1981) cites reports of the presence or abundance of paddlefish before 1900 in the upper reaches and larger tributaries of the Ohio River in Ohio and Pennsylvania, but that soon after impoundment the species decreased markedly. He also noted that before 1880 several sources indicated that paddlefish were abundant in the Scioto River at Columbus, Ohio. Additionally, he stated that paddlefish were reported above Marietta in the Ohio River (near the mouth of Muskingum River in present day Belleville Pool; upper reach) before 1925. Trautman (1981) goes on to state that paddlefish were reduced in abundance in the Ohio River between 1925 and 1950, but that during that period it was most numerous west of Portsmouth (i.e., west of the mouth of the Scioto River). This abundance pattern may have been evident before impoundment as well; for example, Jordan (1882; in Pearson and Krumholz 1984) noted that paddlefish were more abundant in the "lower Ohio River of Ohio" (presumably as compared to the upper Ohio River of Ohio).

Wallus et al. (1990) reported that paddlefish were formerly abundant in the Ohio River and several large tributaries including the Tennessee, Cumberland, and Wabash Rivers. Smith (1979) reported that older commercial fishermen had caught large numbers of paddlefish in the Wabash River, but that they are now rare. Wallus et al. (1990) also noted that paddlefish occur in the Ohio, Great Miami, Scioto, Tennessee, Cumberland, Green, Salt, Kentucky, Licking, Little Sandy, and Kanawha Rivers. Additionally, they noted that paddlefish occur throughout mainstem reservoirs and larger tributaries of the Tennessee and Cumberland River Systems. Henley et al. (2001) reported that paddlefish taken from the Tennessee and Cumberland Rivers represented a large portion of historical harvest.

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that paddlefish were collected occasionally in the lower and middle reach pools (i.e., Meyers to Greenup Pool), occasionally in the Racine Pool (upper reach), and uncommonly in the Pike Island Pool (upper reach; Appendix B). These data sets included recent observations of paddlefish above ORKm 690 including observations in the Meldahl (last record 1995; OEPA unpublished data); Greenup (last record 1995; ORSANCO unpublished data); Racine (last record 1997; ORSANCO unpublished data); and Pike Island Pools (last record 1992; ORSANCO unpublished data). The recent records in the upper pools (i.e., Racine and Pike Island Pools) may be a result of the stocking of paddlefish in the upper Ohio and Kanawha Rivers in the early 1990s (Henley et al. 2001). However, reproduction is occurring in the system as indicated by the capture of larval paddlefish in McAlpine Pool in 1977 (Pearson and Krumholz 1984) and in Meldhal Pool in 1994 and 1995 (Johnson et al. 1997). Johnson et al. (1997) suggested that based on developmental stage, the larval that they captured might have originated from Meldahl or possibly Greenup Pool. Abundance of paddlefish in ORSANCO lock rotenone samples was variable during a 45-year period between 1957 and 1997, with relatively high abundance occurring in the late 1950s, late 1970s, and again in the early 1990s (Lowman 2001).

This information suggests that the present distribution of paddlefish in the mainstem Ohio River is similar to the historical distribution (i.e., mouth to about Pike Island Pool); however, abundance is probably reduced and occurrences above the Greenup Dam are rare. Pearson and Krumholz (1984) suggested a downstream shift in the distribution of paddlefish because at the time of their report no paddlefish had been reported above ORKm 690 (in Meldahl Pool) since 1970. They suggested that this shift might have resulted because of pollution in the upper river or because of restricted fish passage at the mainstem dams. Paddlefish may have expanded their range above Meldahl Pool over the past 30 years by a gradual immigration upstream as permitted by improved water quality (Pearson and Pearson 1989). However, stocking of paddlefish in the upper Ohio and Kanawha (enters R. C. Byrd Pool) Rivers in the early 1990s (Henley et al. 2001) may be responsible for the reports of paddlefish in these upper pools. Johnson et al. (1997) suggested that the upper Ohio River is at the fringe of the native range for paddlefish. This suggests that paddlefish abundance in the upper four to six navigation pools (i.e., Pittsburgh District pools) has always been limited. As noted previously, this is also supported by Jordan's (1882; in Pearson and Krumholz 1984) observation that paddlefish were more abundant in the "lower Ohio River of Ohio."

Life history characteristics and recent literature on the movements of paddlefish suggest that they are highly dependent on upstream migrations for successful reproduction and thus probably affected by restricted passage opportunities at mainstem dams. Their estimated swimming capabilities and pelagic nature indicate that they should be able to take advantage of

any low current zones that may exist in the upper portions of the gate bays and thus possibly pass through the mainstem dams during open river. This is supported by several studies that have noted paddlefish movement upstream through navigation dams (Southhall and Hubert 1984; Moen et al. 1992; Johnson et al. 1997; Conover and Grady 2000; Zigler et al. 2003), including the Meldahl Dam on the Ohio River; many of these studies also suggest that upstream movement through dams by paddlefish occurs during open river.

Paddlefish migrate and spawn at relatively low water temperatures; this may allow them to take advantage of the peak open-river period at the dams, particularly at lower reach dams that open more frequently (Appendix B). However, open-river frequency and duration and hence passage opportunities are moderate to low at middle and upper reach dams (i.e., Huntington and Pittsburgh District dams). This limited opportunity may have substantial implications for paddlefish populations, particularly so if the middle and upper reaches of the Ohio River and associated tributaries (e.g., Scioto, Muskingum, and Kanawha Rivers) comprise the historical spawning habitat for paddlefish in the system. However, as with other litho-pelagophils that spawn over gravel-cobble substrates in flowing water, the creation of reservoirs and their associated sedimentation and reduction in water velocity may be an equally limiting factor for paddlefish populations because of the loss of spawning habitat (Pearson and Krumholz 1984). Obviously, the consideration of upstream fish passage and availability of spawning habitats must go hand-in-hand when planning restoration efforts for paddlefish in the Ohio River.

Goldeye and mooneye *(hiodontids)* are both pelagic, fluvial-dependent species characteristic of large river systems (Pflieger 1971 in Simon and Emery 1995; Galat and Zweimüller 2001). As well, both species spawn over gravel-rock substrates and their embryos develop as they drift (i.e., nonguarder, litho-pelagophil). Mooneye spawn in fast water in large clear streams and in the tailwaters of dams (Trautman 1981; Wallus et al. 1990). Goldeye may be more generalists in regards to spawning habitat as compared to mooneye. Lee et al. (1980) reports that goldeye spawn in pools of rivers or backwaters of lakes, while others report that goldeye ascend tributary streams and spawn over gravel shoals (Smith 1979; Wallus et al. 1990), or in shallow inshore areas of lakes, pools of turbid rivers, and backwater lakes and ponds of rivers (Wallus et al. 1990). Both species are thought to migrate to spawn in the spring at water temperatures of about 10 to 20°C (Smith 1979; Trautman 1981; Wallus et al. 1990). Mooneye may generally spawn earlier in spring than goldeye as indicated by the lower range of reported spawning temperatures (Table 12).

Estimates of prolonged swimming speed for both species based on observations of goldeye in two separate studies (Jones et al. 1974; Tunink 1975) were 0.8 m/s and 0.6 m/s (Table 8). Burst speeds for both species based on a study of American shad were 3.47 to 4.15 m/s (Weaver 1965). Maximum swimming speed estimates (U_{max}) ranged from 2.56 to 4.20 m/s at temperatures of 9 to 15°C for both species as determined by methods of Winter and Van Densen (2001; Table 8).

The upper Ohio River defines the eastern native range for mooneye and goldeye; however, their range extends north and south of the Ohio River Basin (Lee et al. 1980). In their review of data and literature, Pearson and Pearson (1989) found that goldeye and mooneye were present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). Pearson and Krumholz (1984) point out the similarity in abundance and distribution of these two species in the Ohio River and suggested that neither species was

abundant historically. Pearson and Krumholz (1984) also stated that the goldeye are commonly seen but never in abundance. They stated that the goldeye were never as abundant as the skipjack herring and that others suggested that goldeye numbers were reduced. The only recent records (1979 and 1981) they found of goldeye above ORKm 269 (in Belleville Pool) were at ORKm 87 (New Cumberland Lock) and ORKm 124 (in New Cumberland Pool). Pearson and Krumholz (1984) indicated that mooneye were present in the Ohio River upstream to the mouth of the Muskingum River (enters Belleville Pool; ORKm 277) between 1920 and 1969; however, they found no reports of mooneye since 1970 in the reach above ORKm 418 (in R. C. Byrd Pool). Pearson and Pearson (1989), however, indicated that the mooneye appear to be expanding their distribution as demonstrated by occurrences between ORKm 418 and ORKm 87 since 1983.

Henshaw (1888 in Trautman 1981) indicated that goldeye were present in the Ohio River presumably near Cincinnati, Ohio (Markland Pool; about ORKm 750). Trautman (1981) noted that fishermen reported goldeye occasionally present to the Pennsylvania state line (presumably around 1920), particularly during spring. Trautman (1981) described the abundance and distribution of goldeye in Ohio as extending along the entire border; however, he noted that they were most abundant in the Scioto River and in the Ohio River from the mouth of the Scioto River (ORKm 570) westward. He also noted their presence in the Muskingum and Little Miami Rivers. Trautman (1981) suggested that goldeye had become more abundant relative to the mooneye since 1920, possibly because of the goldeye's greater tolerance of high turbidity. He also noted that the distribution of goldeye between 1955 and 1980 did not change relative to their distribution pattern in 1950.

Forbes and Richardson (1908 in Smith 1979) noted that goldeye were formerly common in the Ohio River in Illinois, but rare at the time of their field work. Smith (1979) indicated that goldeye are now uncommon in the Ohio and Wabash Rivers in Illinois. Clay (1975) indicated that goldeye are present in the Ohio River in Kentucky, and in the lower reaches of major tributaries including the Green River (enters J. T. Myers Pool), Salt River (enters Cannelton Pool), Cumberland River (enters Pool 52), and middle fork of Kentucky River (enters McAlpine Pool). Clay (1975) also noted that goldeye had been extirpated from the upper Tennessee and Cumberland Rivers. Wallus et al. (1990) cited two reports that indicated goldeye were commonly present (in small numbers) in samples from the Ohio River collected between 1977 and 1986 from ORKm 418 and ORKm 795, but infrequent in samples from the lower Ohio River. He also cites Etnier and Starnes (no date) indicating that goldeye were found in the upper Tennessee and Cumberland Rivers before impoundment, but have since disappeared.

Kirtland (1847 in Trautman 1981) and Henshall (1888 in Trautman 1981) indicated that mooneye were common in the Ohio River before 1900, but did not give reach-specific information. Trautman (1981) noted that during extensive field work between 1920 and 1935, he collected no mooneye in the Ohio River west of Adams County (Meldahl Pool; middle reach) and that only a few individuals were collected east of Adams County (lower Meldahl and upper Markland Pools). However, he stated that during this period mooneye were still abundant in the lower Scioto River (enters Meldahl Pool; upper margin of the middle reach), but that numbers had markedly declined since 1935. Forbes and Richardson (1908 in Smith 1979) reported that mooneye were formerly common in the Ohio River (presumably along Illinois), but rare at the time of their field work. Smith (1979) indicated that mooneye were presently uncommon in the Ohio and Wabash Rivers in Illinois. Environmental Science and Engineering, Inc. (1987 in Wallus et al. 1990) indicated that mooneye were present in small numbers in gill net samples at

ORKm 418 and ORKm 795 from 1977 to 1986 (all years). Wallus et al. (1990) also noted that mooneye were occasional to rare in the Green River (enters J. T. Myers Pool; lower reach) and occasional to common in the reservoirs of the Tennessee and Cumberland Rivers (enter Pool 52; lower reach). Clay (1975) stated that mooneye were more abundant in the Ohio River in western Kentucky as compared to eastern Kentucky.

Our examination of recent survey data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data) indicated that goldeye were generally occasional to common in samples from Smithland to Markland Pool (lower and middle reaches), and generally absent from R. C. Byrd to Emsworth Pool (upper reach; Appendix B). Analysis of the ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) indicated that the abundance of goldeye was variable across years with no significant trends in any of the three sections of the Ohio River (upper—ORKm 0 to 327; middle—ORKm 327 to 1,134; and lower—ORKm 1,142 to 1,578; however, note the difference between these sections and the reaches defined by Pearson and Pearson [1989]) and that relatively high catches were noted periodically including in the 1950s, 1970s, and 1990s. In our examination of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found mooneye to be more widely distributed and generally more common than goldeye (Appendix B). Mooneye were generally common in collections from Smithland to Racine Pool (lower and middle reaches and lower margin of the upper reach), and occasional from Belleville to Dashields Pool (upper reach). Analysis of the ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) indicated that mooneye were increasing in all three sections of the Ohio River.

This information suggests that goldeye and mooneye have persisted in the Ohio River System despite the presence of dams. Their apparent greater abundance and wider distribution in the lower reaches of the Ohio River, as compared to the upper reach, suggest that lack of fish passage may adversely affect both species. However, historical information, albeit qualitative, suggests that goldeye and mooneye may have declined before impoundment (Smith 1979; Trautman 1981) probably as a result of increased turbidity and pollution. Recent data suggest that these populations have expanded their range or increased in abundance (Pearson and Pearson 1989; Lowman 2000; Appendix B) probably because of improvements in water quality brought about by the Clean Water Act (Van Hassel et al. 1988; Pearson and Pearson 1989). Again, the qualitative nature and general lack of historical data, along with the concomitant nature of environmental stressors acting on these populations, make it difficult to assess the relative role of fish passage in affecting goldeye and mooneye populations. However, if we accept these historical assessments as correct and take into account the recent expansions in abundance and distribution of these populations, then poor water quality rather than lack of fish passage probably played a larger role in their early declines. Regardless, now that water quality has improved, improvements in upstream fish passage may further benefit goldeye and mooneye populations.

Life history characteristics of goldeye and mooneye (e.g., migratory, drifting embryos, large-river fauna) imply that both species should benefit from upstream passage through mainstem dams. The relatively high swimming speed estimates and pelagic nature of goldeye and mooneye suggest that they should be capable of moving through mainstem dams during open river; however, to our knowledge no information is available that documents such movements. Based on spawning temperatures, both species probably begin to migrate early, but mooneye have a narrower range of reported spawning temperatures (Table 12), thus may be obligated to move sooner than the goldeye. This suggests that both species can take advantage

of the peak open-river period in the lower reaches of the Ohio River to pass through dams, but that mooneye may have a slight advantage over goldeye because mooneye may be more likely to encounter open-river conditions at the dams during earlier migrations (Table 9; Appendix B).

American eel are a benthic catadromous species that migrate from the Mississippi River and other East Coast drainages to the Sargasso Sea in the Atlantic Ocean to spawn in late winter to early spring and then die (Smith 1979; Wallus et al. 1990, Stauffer et al. 1994; Haro et al. 2000). The larvae passively drift back toward the East Coast of North and South America and develop into elvers (Avise et al. 1986 in Haro et al. 2000). After reaching the coast, female elvers migrate far upstream into large river systems to feed and mature, while males remain in the lower reaches (Pflieger 1975; Lee et al. 1980). Females reach sexual maturity in 5 to 20 years and at a total length of about 457 mm (Becker 1983) before migrating out of rivers and back to the Sargasso Sea. The population is thought to be panmictic (i.e., mature adults migrate from numerous watershed, meet in the Sargasso Sea, and spawn together), thus recruitment in a particular watershed, such as the Ohio River Basin, is not necessarily dependent on the production of adults from that watershed (Haro et al. 2000).

We found no species-specific information on the swimming speeds of American eel, but McCleave (1980) reported that European eel elvers would probably not make progress in water velocities >0.5 m/s. Estimated burst speed of adult-sized American eel was based on work with the European eel (Blaxter and Dickson 1958) and was 1.14 m/s. Estimated burst speeds of adult-sized American eel based on the methods of Winter and Van Densen (2001) were 1.81 and 3.63 m/s at 15 and 25°C, respectively. Female eels are known to move over land on wet nights, potentially allowing them to pass obstacles, such as dams (Stauffer et al. 1994).

The Ohio River drainage is central to the native range of the American eel (Lee et al. 1980). However, East Coast watersheds represent the relative stronghold for remaining numbers. Pearson and Pearson (1989) suggest that the historical distribution of American eel in the Ohio River Basin is largely unknown. They found records of the species in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578) in an early (1800 to 1969) and recent period (post-1969; Appendix B). Pearson and Krumholz (1984) noted that there were no records of American eel above ORKm 277 (in Belleville Pool) between 1920 and 1969 and that the four recent records (post-1969) represent a return to this reach of the river because of improved physicochemical conditions (presumably from a reduction in pollution).

Rafinesque (1820 in Trautman 1981) noted the presence of American eel as far upstream in the Ohio River as Pittsburgh. Kirtland (1850 in Trautman 1981) stated that American eel ascend the Ohio River drainage to "even its head during spring." Trautman (1981) reported that American eel were "rather numerous" between 1920 and 1950 in the Ohio River as far upstream as Marietta (mouth of the Muskingum), in the lower Scioto River (enters Meldahl Pool), and in the Muskingum River (enters Belleville Pool). He also noted their presence in 1968 and 1969 (as reported to him by H. Ronald Preston) at four of nine collection stations on the Ohio River between Belmont and Clermont counties (Markland through Hannibal Pool; middle to upper reach). Smith (1979) suggests that the American eel are now rare in Illinois and is most often found in large rivers. His map depicting the distribution of American eel indicated that it was reported from the Wabash River and a tributary of the Wabash River, but not from the mainstem of the Ohio River along Illinois. Smith (1979) suggests that the construction of dams has greatly

reduced American eel numbers in Illinois. Clay (1975) noted that American eel enter Kentucky streams from the Ohio River, but that their movements are inhibited by large dams.

Our examination of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data) indicates that American eel are generally collected occasionally from the Smithland to Markland Pool (lower and middle reaches), and generally uncommon to absent in the remaining upstream pools (Appendix B). In the lower reach, American eel were commonly collected in the Smithland Dam lock surveys, with the most recent specimens captured in 1997. The most recent records in the upper reach of the river were from the New Cumberland (in 1988) and Racine (in 1989) lock chambers (ORSANCO unpublished data).

This information on abundance and distribution suggests that dams generally block movements of American eel in the Ohio River and that the resulting cumulative effect of blockage is the general absence of the species in the upper reaches of the system. This hypothesis is supported by the swimming speed and life history information reported for American eel. We found little information regarding the migration period of American eel in the Ohio River, but an early report (Kirkland 1850 in Trautman 1981) suggests an upstream migration in the spring. Although this migration period corresponds to the peak period for open river, the poor swimming ability and benthic nature of the species may prevent them from moving upstream through open dams. As well, they are catadromous, and landlocked populations are not known. Thus, American eel must move through or around dams to be present in the upper reaches of the Ohio River. A recent decline in this species has been noted for a broad geographic area in North America, and obstruction of migratory pathways by dams has been implicated as a probable cause in several watersheds (Haro et al. 2000). However, despite dams, American eel have persisted in regulated rivers, including the Ohio River. Thus, other factors (e.g., harvest, oceanic variation, contaminants, and disease) may be acting in concert with dams to affect population levels (Haro et al. 2000). The recent reports of American eel in the Ohio River may be the result of upstream passage through the locks or movement around these dams on wet surfaces by a few individuals. Given a panmictic population, individuals reported in the Ohio River may be offspring from adults that were reared elsewhere (e.g., the lower portions of the Mississippi River Basin, Gulf Coast streams, or Atlantic Coast streams), rather than from the apparently meager number of American eel now reaching maturity in the Ohio River.

The obvious need for upstream passage in order for American eel to be present in the Ohio River (i.e., recruits must come from the ocean) and the apparent decline in their numbers probably in part because of dams, argues strongly for implementation of measures to improve passage at these dams in order to enhance their population. Although some passage still occurs, directed measures to improve passage could benefit American eel in the Ohio River. Large numbers of American eel and European eel are known to pass through conventional fish and eel-specific passage structures, sometimes with great success (Haro et al. 2000). As well, American eel are habitat generalists and thus would probably be able to meet feeding and overwintering requirements if they are able to move into the impoundments in the Ohio River.

Factors that may counteract population increases despite implementation of passage measures include yet unconfirmed (e.g., overharvest, oceanic variation, contaminants, and disease) or unidentified factors causing the general decline in American eel numbers throughout their native range (East Coast of North America and northern South America; Haro et al. 2000). The relatively recent discovery that the Gulf hypoxic zone is growing may also deter recovery of American eel by blocking access to the Mississippi River. The qualitative nature of the historical

data on abundance and distribution does not provide the level of detail necessary to assess whether or not the Ohio River was ever more than a marginal watershed for the American eel. An examination or understanding of oceanic currents or American eel densities in other Gulf Coast watersheds over time may provide some answers to this question by determining the degree to which these currents are favorable to elver drift into these systems. Given the panmictic nature of the American eel population, one can imagine that under certain oceanic conditions (water currents) Gulf Coast watersheds, including the Ohio River Basin, may have been important sources of adult American eel and thus may have contributed to the relative stability of the population.

Alabama shad are a pelagic, anadromous species that migrate into the Mississippi River Basin and other Gulf Coast rivers to spawn in January to July when water temperatures reach 19 to 22°C (Clay 1975; Smith 1979; Lee et al. 1980; National Oceanic and Atmospheric Administration [NOAA] 2001). Spawning occurs over coarse sand, gravel, and rock substrates in moderate current (Lee et al. 1980; NOAA 2001). Adult fish return to the ocean shortly after spawning. Alabama shad sexually mature at 25 to 45 cm total length (Pflieger 1975). The average age of spawning fish is 2 years, and up to 38% of individuals are thought to be return spawners (NOAA 2001). Young remain in rivers for 6 to 8 months before migrating back to the Gulf of Mexico (NOAA 2001); little is known about their distribution once they return to sea (Clay 1975).

Lee et al. (1980) indicated that Alabama shad were formerly in the mainstem and major tributaries of the lower Mississippi River, but are now considered rare in this drainage possibly because of dams and increased siltation. Their former distribution included reports from the mainstem of the Ohio River at Louisville, Kentucky and in the Cumberland River (Lee et al. 1980). Pearson and Krumholz (1984) noted that the only report of Alabama shad in the Ohio River was by Everman (1902 in Pearson and Krumholz 1984) who reported them at Louisville, Kentucky, in 1897 and 1898. They stated that Alabama shad are not probably present in the Ohio River today. Clay (1975) noted other reports of Alabama shad from the Louisville area in the late 1800s. As well, he noted reports of the Ohio shad (*Alosa ohiensis*), now thought to be the same species as the Alabama shad, as far upstream as the mouth of the Kanawha River (enters R. C. Byrd Pool) in the 1800s. Wallus et al. (1990) reported that Alabama shad were present in large rivers in Tennessee, but that they were "not able to cope with impoundments," suggesting they have been extirpated; however, they do not cite references to support these contentions. The NOAA (2001) reported that Alabama shad supported a commercial fishery in the Ohio River in the 1800s; however, this source does not provide a specific reference for this information. Furthermore, Clay (1975) noted the likelihood of non- or misidentification of "shad" species found in the Ohio River in the 1800s and that American shad (*Alosa sapidissima*) were stocked and supported at least a limited fishery in the Ohio River at that time. The dearth of historical reports for Alabama shad in the Ohio River drainage may imply that the Ohio River was always marginal range for the species. Conversely, the species may have been more abundant than indicated by these reports given the likelihood of non- or misidentification of shad-like species in general (see Clay 1975).

Alabama shad is one of two *Alosa* species native to the Ohio River, the other one being the skipjack herring. However, unlike skipjack herring, Alabama shad cannot complete their entire life cycle in freshwater, and adults and juveniles must return to the ocean to feed and mature. Thus, the presence of adults and juveniles in the Ohio River or its tributaries is

dependent on the adults' ability to move upstream through mainstem dams on a regular basis and the ability of juveniles to pass safely downstream through dams. Estimates of their swimming speed and pelagic and migratory nature suggest that Alabama shad should be capable and motivated to move upstream through mainstem dams on the Ohio River. Their absence despite the continued persistence of other similarly capable and motivated potadromous species (e.g., skipjack herring, goldeye, and mooneye) suggests that upstream passage may be somewhat restricted for all of these species. However, local populations and metapopulation dynamics (Stanford et al. 1996) of the potadromous species are probably responsible for their wide distribution and persistence, whereas Alabama shad need to move through mainstem dams on a regular basis (ideally annually) to persist in the system.

This information suggests that any recovery of Alabama shad would be dependent on measures to improve upstream fish passage in the Ohio River and possibly in its tributaries. However, the general decline of Alabama shad in the lower Mississippi River as noted previously may preclude recovery in the Ohio River. Conversely, if the upper Ohio River was an important traditional spawning area, then improving upstream passage in the Ohio River may provide a mechanism for recovery systemwide, including the lower Mississippi River. In such a scenario, describing the characteristics of spawning habitat used by remaining populations of Alabama shad may help identify traditional areas in the Ohio River or direct construction of artificial spawning habitat. Another consideration in the recovery of the Alabama shad is safe downstream passage. Young reportedly return to the sea within 6 to 8 months of hatching. The consequences of increased mortality or delayed emigration associated with downstream passage through dams are unknown. However, in salmon populations, downstream passage of juveniles is now thought to be as significant as upstream passage of adults in terms of population viability.

Skipjack herring are a pelagic, fluvial-dependent species that are characteristic of large rivers (Pflieger 1971 in Simon and Emery 1995). Skipjack herring occur in high flow areas over gravel and sand in large rivers (Smith 1979), but may avoid turbid water (Trautman 1981). Skipjack herring have a prolonged spawning season (Lee et al. 1980), reportedly between March and June in Tennessee (Wallus et al. 1990). They are thought to be phyto-lithophils preferring to spawn over vegetation, or secondarily over gravel, rock, or logs (Wallus et al. 1990). However, Lee et al. (1980) noted that skipjack herring probably spawn in the depths of the main channel over coarse sand-gravel bars. Skipjack herring in spawning condition have been collected in headwater tributaries, tailwaters, and reservoirs of the Tennessee River (Wallus et al. 1990). Skipjack herring reach sexual maturity in 2 to 3 years and at total lengths of 254 to 381 mm (Clay 1975; Becker 1983; Wallus et al. 1990). They are thought to be highly or at least somewhat migratory (Smith 1979; Lee et al. 1980); several authors have noted that skipjack herring migrate upstream in the spring and gather in large numbers below dams (Clay 1975; Smith 1979; Wallus et al. 1990); however, they generally are not reported in small rivers and streams.

Species-specific information on the swimming speed of skipjack herring was not found. Based on goldeye swimming performance (Tunink 1975), the estimate of prolonged swimming speed (U_{crit10}) for skipjack herring was 0.8 m/s (Table 8). The estimate of skipjack herring burst speed, based on the American shad (Weaver 1965), was 3.47 to 4.15 m/s; these estimates closely match the estimates of maximum swimming speeds (U_{max}) based on the methods of Winter and Van Densen (2001) which were 3.75 and 4.31 m/s at 13 and 15°C, respectively.

The Ohio River Basin is central to the original latitudinal distribution of the skipjack herring; however the upper Ohio River is the eastern limit of its native range (Lee et al. 1980). Pearson and Pearson (1989) found that skipjack herring were present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). Pearson and Krumholz (1984) noted that skipjack herring were probably abundant before 1900, and that despite severe pollution in the early to mid-1900s managed to persist throughout the river. Trautman (1981) cited Rafinesque (1820), Kirkland (1851), and Henshaw (1888) noting that skipjack herring were present to abundant in the Ohio River before 1900. Rafinesque (1820 in Trautman 1981) noted that skipjack herring generally were not found as far up river as Pittsburgh and that they do not ascend small streams. Trautman (1981) noted that between 1920 and 1950 skipjack herring were more abundant in the Ohio River below Marietta (mouth of the Muskingum River in Belleville Pool) than in two tributaries (i.e., lower Scioto and Muskingum Rivers) or in the Ohio River above Marietta to Pittsburgh. Trautman (1981) indicated that between 1955 and 1980 the distribution of skipjack herring generally did not change and was presumably similar to the pre-1955 distribution. Smith (1979) indicated that skipjack herring were more common in the Ohio and Wabash Rivers than in the Mississippi and Illinois Rivers. He also noted that skipjack herring are still occasionally taken in the Upper Mississippi River below Pool 25 (i.e., in Pool 26, the pool formed by the downstream-most dam in the system) and in the Illinois River. Coker (1930) stated that skipjack herring were "enormously abundant" at Keokuk, Iowa until the construction of Lock and Dam 19 at Keokuk. Clay (1975) noted that skipjack herring were present as far upstream in the Ohio River as Pennsylvania and that they also occur in the Tennessee, Cumberland, Green, and Little Sandy Rivers in Kentucky. Wallus et al. (1990) noted that adult skipjack herring also occur in large tributaries and mainstem reservoirs of the Tennessee River System.

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found skipjack herring to be commonly taken from the mouth of the Ohio River to Belleville Pool and occasionally to commonly collected in the upper seven pools (Appendix B). Our findings are in general agreement with the historical data presented above, in that skipjack herring were more common in the Ohio River below the mouth of the Muskingum River as compared to above this mouth. In analysis of the ORSANCO lock rotenone data (1957 to1997), Lowman (2000) found that skipjack herring showed a significant increasing trend in all three sections of the Ohio River (upper—ORKm 0 to 327; middle—ORKm 327 to 1,134; and lower—ORKm 1,142 to 1,578; however, note the difference between these sections and the reaches defined by Pearson and Pearson [1989]).

Based on abundance and distribution information, skipjack herring have done and apparently are doing well in the Ohio River despite mainstem dams and historical periods of severe pollution. Skipjack herring are probably capable and motivated to move through open mainstem dams based on their relatively high swimming speeds (Table 8) and life history characteristics (i.e., pelagic, fluvial-dependent, characteristic of large rivers, migrate upstream to spawn, and slightly to highly migratory; Table 12). As well, the literature indicated that they have a prolonged spawning period, which would suggest that they could take advantage of open river periods in the Louisville District (Appendix B). However, movement through dams in the Huntington and Pittsburgh Districts are probably low to non-existent based on the frequency of open-river conditions.

The persistence of skipjack herring in the upper Ohio River versus its apparent extirpation in the impounded reaches of the Upper Mississippi River at first seems contradictive. Coker (1930) noted a substantial decline in the abundance of skipjack herring in the Upper Mississippi River above Lock and Dam 19 after the completion of that dam. Dam 19 rarely opens and thus is thought to be a nearly complete barrier to fish passage (Wilcox et al. unpublished report). This suggests that an analogous decline in skipjack herring should have occurred in the upper and middle reaches of the Ohio River where dams open infrequently (Table 9). However, this decline has not occurred suggesting that successful reproduction of local populations rather than upstream fish passage is responsible for maintaining the abundance and distribution of skipjack herring in the Ohio River. Although skipjack herring could have reproduced above Lock and Dam 19 in the Upper Mississippi River, this species may not persist there because the reach above that dam represents the northern extent of the skipjack herring's native range (Lee et al. 1980). This information suggests that skipjack herring were unable to consistently overwinter in that reach of the river and thus their presence was dependent on upstream movement through dams. In support of that hypothesis, the latitude above Lock and Dam 19 on the Upper Mississippi River is generally greater than the latitude at Pittsburgh (source of the Ohio River). As well, the latitude at Lock and Dam 25 on the Upper Mississippi River, above which skipjack herring rarely occur today, is nearly equivalent to or greater than the latitude at the confluence of the Ohio and Muskingum Rivers; as noted previously, skipjack herring have apparently always been more common in the Ohio River below the mouth of the Muskingum River as compared to above, suggesting that this reach above the mouth of the Muskingum River is approaching their latitudinal limit.

Bighead and silver carp are non-native potentially invasive species that occur in large river systems in their native range in eastern Asia (U.S. Fish and Wildlife Service [USFWS] 2000). Bighead carp are benthopelagic, while silver carp are primarily pelagic. Both species are generally considered filter feeders with bighead carp considered as omnivorous plankton feeders, while silver carp consume primarily phytoplankton (Dong and Li 1994). Bighead carp have also been reported as opportunistic bottom feeders (Opuszynski et al. 1991). Bighead and silver carp feeding habits overlap significantly with several native species of fish (e.g., paddlefish, bigmouth buffalo, and gizzard shad *Dorosoma cepedianum*) and freshwater mussels raising concern about negative impacts (USFWS 2000). The presence of stocked bighead and silver carp was noted as a driving force in determining the structure of copepod communities in a subtropical Chinese lake (Xie and Yang 2000).

Bighead and silver carp migrate upstream in spring to spawn at water temperatures of 18 to 30°C, and eggs and larvae drift until hatching (USFWS 2000) suggesting that these species are pelagophils or litho-pelagophils. Schrank et al. (2001) found that bighead carp spawned in the unimpounded reach of the Missouri River (in Missouri and Kansas) during three distinct periods from mid June to early July in conjunction with rising discharge and water temperatures above 22°C. They suggested that a combination of water temperature and discharge act as a cue for spawning and that these conditions possibly ensure successful hatching. In Missouri, bighead carp reportedly congregate on mud flats and shallow confluences (presumably in preparation for spawning) when waters warm (USFWS 2000). Lin Z (1991 in USFWS 2000) reported that bighead carp spawn in two habitat types, either canyons or river valleys. In canyons, spawning occurs in depths of up to 40 m with water velocities from 1.3 to 2.5 m/s. In river valleys, bighead carp spawn at meanders, sandbars, and rocks extending into the river. Lin Z (1991 in

USFWS 2000) also suggested that bighead and silver carp may be cued to spawn by rising water levels.

Little information was found as to the extent of upstream migrations or as to the importance of these migrations in the success of bighead and silver carp populations. In the Terek Region of the Caspian Basin, non-native bighead and silver carp larvae and fingerlings migrated (presumably in a passive manner) to the coastal areas of the Caspian Sea; after maturing, these fish moved back upstream 125 to 260 km to spawn (Abdusamadov 1986). Yi et al. (1991) noted that native bighead and silver carp in the Yangtze River in China are semi-migratory and that some populations of these fishes were affected by the construction of a mainstem dam between the upper and middle reaches of that river. However, they noted that because of the wide geographic dispersion of 36 spawning sites along this reach of the river (1,695 km), no overall affect to the metapopulation was anticipated. This information suggests that both species can persist in rivers with mainstem dams that prevent upstream migrations when local upstream populations are present.

Prolonged and burst swimming speed estimates for bighead and silver carp are based on the common carp (Videler 1993; Blaxter 1969) and were 0.83 and 1.75 m/s, respectively. The estimate of prolonged swimming speed may be low because it was based on the performance of small common carp (i.e., 15 cm; Videler 1993). As well, the reported water velocities in spawning areas of bighead carp (i.e., 1.3 to 2.5 m/s; Lin Z 1991 in USFWS 2000) suggest that prolonged and burst speed estimates may be low. Further suggesting that these fish are relatively fast swimmers, Wang (1985) noted that adult bighead and silver carp were difficult to capture with trawl nets of traditional mesh size, whereas by switching to a trawl with larger mesh size (presumably allowing for faster tow speeds) success was improved. The maximum swimming speeds (U_{max}) determined with methods of Winter and Van Densen (2001; Equation 1) were 4.5 and 3.1 m/s at 21 and 15°C, respectively for both species (Table 8).

Bighead and silver carp were introduced into the United States in the early 1970s in association with aquaculture and have since become established in the Mississippi River Basin (USFWS 2000). Populations of reproducing bighead or silver carp have been reported in the Illinois, Mississippi, and Missouri Rivers (Tucker et al. 1996; Schank et al. 2001). Pearson and Pearson (1989) found that silver carp were not reported in any reach of the Ohio River before 1970; however, silver carp were present in the lower and middle reaches after 1970. Pearson and Krumholz (1984) noted that one specimen had been collected at the Falls of Ohio (in the Cannelton Pool). No mention of bighead carp appears in Pearson and Pearson (1989) or Pearson and Krumholz (1984), presumably because it did not occur in the Ohio River at the time. The earliest report in the U.S. Geological Survey's Nonindigenous Aquatic Species Database for bighead carp in the Ohio River was in 1997 at Moundsville, West Virginia (Hannibal Pool; U.S. Geological Survey [USGS] 2003). Other reported locations in the Ohio River include McAlpine Pool (1998) and Pike Island Pool (2002). The earliest report in the U.S. Geological Survey's Nonindigenous Aquatic Species Database for silver carp in the Ohio River was in 1984 at the Falls of Ohio in the Cannelton Pool (USGS 2003). Other reported locations in the Ohio River include at the J. T. Myers Dam (1986 and 1991) and in the southeast corner of Indiana (possibly Markland or McAlpine Pool) in 1992. The USFWS (2000) indicated that the silver carp was present from the mouth of the Ohio River to the J. T. Myers Dam, and that bighead carp were present from the mouth to the McAlpine Dam. As well, bighead carp were reported as present in the Cumberland River below Barkley Dam and in the lower Green River below Lock and Dam 3 (USFWS 2000). We found no records of silver carp in the post-1988 lock rotenone

or night electrofishing data sets (ORSANCO unpublished data; OEPA unpublished data); however, bighead carp were collected in the J. T. Myers Pool in 1997.

Bighead and silver carp are probably capable and motivated to move upstream through open navigation dams based on their swimming speeds and life history characteristics (i.e., benthopelagic or pelagic, fluvial-dependent, pelagophil, and semi-migratory to migratory). If their migratory behavior is generally limited to spawning runs, then they have low to moderate opportunities for upstream passage at mainstem dams in the Louisville and Huntington Districts except at Dams 52 and 53 that are generally open (Appendix B). Passage opportunities at Pittsburgh District dams would be nearly non-existent year round (Table 9), except through locks. If spawning temperatures of bighead carp in the Ohio River are similar to those reported in the Missouri River (i.e., 22°C; Schrank et al. 2001), rather than the broad range reported elsewhere (i.e., 18 to 30°C), then the opportunities for upstream passage would be more limited in the Louisville and Huntington districts because open river conditions are less frequent when water temperatures are greater than 22°C as compared to less than 22°C.

Limited opportunities for upstream passage at upper reach dams may slow the spread of Asian carps into these reaches; however given that some upstream passage probably occurs through lock chambers under normal operating conditions, a brood stock of bighead and silver carp probably would become established. Once established in the upper and middle reaches of the Ohio River, reproductive potential of bighead and silver carp may be high based on their success in other regulated systems unless other factors (e.g., climate) are limiting. Under this scenario, provisions for upstream passage to benefit native species may also speed the range expansion of bighead and silver carp in the Ohio River, but should not necessarily be deterred because the likelihood of the eventual spread of these invasive species is good despite the general lack of upstream passage opportunities.

Blue sucker are benthic, fluvial specialists characteristic of large rivers where they are found in deep channels, pools, riffles, and chutes with current (Smith 1979; Trautman 1981). For example, blue sucker were collected in areas of fast current in Pool 20 of the Upper Mississippi River (Rupprecht and Jahn 1980). Several authors suggested that blue sucker may be intolerant of turbid conditions (Smith 1979; Trautman 1981); however, Lee et al. (1980) suggest this may not be true based on their wide distribution in the Missouri River. Blue sucker are thought to be nonguarder litho-pelagophils (i.e., spawn over rock or gravel) that migrate upstream during spring to spawn in riffles (Lee et al. 1980; Smith 1979; Moss et al. 1983). Spawning occurs at water temperatures of 10 to 23°C (Becker 1983; Stauffer et al. 1994). Specifically, Moss et al. (1983) found that blue sucker from the Neosho River in Kansas spawned in May at 20 to 23°C, whereas Rupprecht and Jahn (1980) collected ripe male blue sucker from Pool 20 in the Upper Mississippi River near the end of April in two separate years at water temperatures of 16.4 and 13.4°C. The youngest mature male blue sucker collected by Rupprecht and Jahn (1980) was age 4 and 503 mm total length, whereas the youngest mature female was age 6 and 573 mm total length.

Smith (1979) noted that blue sucker move long distances into streams and suggested that they may be highly migratory. Blue sucker populations (Mississippi River Basin population and Gulf Coast populations) have recently been divided into two separate species with a proposal for further division into three species (Buth and Mayden 2001). Recent studies of *Cycleptus meridionalis*, the species recently distinguished from blue sucker, indicated that it was highly migratory (Scott Mettee, Geological Survey of Alabama, Tuscaloosa, Alabama, personal

communications). As well, Peterson et al. (1999) noted that *Cycleptus meridionalis* populations are seemingly doing well in the Pearl and Pascagoula Rivers in Mississippi and suggested that this status results because spawning migrations are generally less restricted in theses systems as compared to other more heavily modified (for hydropower and navigation) rivers.

The estimated prolonged (U_{crit10}) and burst swimming speeds of blue sucker were 1.02 and 3.30 m/s based on studies on the longnose sucker (Jones et al. 1974) and the western sucker (Blaxter 1969), respectively (Table 8). The maximum swimming speed based on the methods of Winter and Van Densen (2001; Equation 1) was 5.22 m/s at 15°C. Their common occurrence in fast currents of large rivers also suggests that they are strong and fast swimmers.

The Ohio River defines the eastern limit of the natural distribution of blue sucker, but is central to their latitudinal distribution (Lee et al. 1980). Pearson and Pearson (1989) found that blue sucker were present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). Pearson and Krumholz (1984) suggested that blue sucker were historically abundant but had declined substantially by 1950 and that a recent (post-1975) increase may have occurred. They found only five records of blue sucker in the Ohio River for the period of 1970 to 1982; these records were for fish observed between ORKm 87 (New Cumberland Dam) and ORKm 1,197 (Newburgh Pool). Between 1981 and 1983, W. D. Pearson observed about 300 specimens of blue sucker at the Falls of Ohio (just below McAlpine Dam) during various occasions (Pearson and Krumholz 1984).

Trautman (1981), based on historical references, noted the presence of blue sucker at Pittsburgh and their common occurrence at Cincinnati before 1900. As well, he stated that between 1925 and 1950 blue sucker were most common in the river between the Indiana state line and Portsmouth (middle reach; Markland and Meldahl Pools) and in the lower reaches of the Great Miami (enters Markland Pool), Scioto, and Muskingum Rivers. Trautman (1981) also noted that blue sucker were present in the Ohio River between Portsmouth and Marietta (potentially Meldahl, Greenup, R. C. Byrd, Racine, and Belleville Pools; middle and upper reaches) between 1925 and 1950 and was even rarely taken from Marietta (upper reach near Willow Island Dam) to the Pennsylvania state line. Trautman (1981) stated that personnel from the University of Louisville captured only five specimens from the Ohio River (all from the lower reach; Clay 1975) in 341 samples collected along the entire length of the river, suggesting a decline in abundance as compared to the earlier period (i.e., 1925 to 1950). Between 1955 and 1980, Trautman (1981) reported that personnel with the Ohio Division of Wildlife occasionally captured blue sucker from the lower reaches of the Scioto and Muskingum Rivers (entering middle and upper reaches, respectively).

Smith (1979) noted the presence of blue sucker in the Ohio and Wabash Rivers along Illinois and also suggested a decline from past abundance. He indicated that this decline has been attributed to the construction of dams, deterioration of water quality, overharvest of adults during spawning migrations, and reduction in channel depth through deposition. Clay (1975) noted additional records along the Ohio River in Kentucky during the 1900s including in the lower reach (1959) and in the Licking River (enters middle reach; 1940 and 1956). As well, he notes a report from the Cumberland River (Woolman 1892 in Clay 1975). Clay (1975) suggested that although the life history requirements of the species are not well known, the probable causes of their apparent decline include siltation, pollution, and possibly conversion of lotic areas to "semi-lentic" areas. This conversion probably eliminated much of the habitat preferred by blue sucker (i.e., deep-channel, high-current areas over sand or gravel substrates).

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that blue sucker were generally absent from samples. Blue sucker were sampled occasionally in the Newburgh and Cannelton Pools and uncommonly in the Markland Pool. However given that blue sucker are typically found in deep channels with fast current, the sampling methods used in the ORSANCO (unpublished data) and OEPA (unpublished data) surveys (lock rotenone sampling and night electrofishing) are probably ineffective at capturing blue sucker. Pearson and Pearson (1989) suggested that the abundance of blue sucker had increased in the upper and middle reaches as compared to 1970 levels. However, whether or not this trend has continued is uncertain because of the noted limitation of the recent data we analyzed.

If accurate despite the limitations of the data, the present distribution of blue sucker in the Ohio River may be related to passage opportunities at dams, with occasional occurrence in the lower pools where passage opportunities exist, and absence from upper pools where passage opportunities are rare (Appendix B). Smith (1979) suggested that dams that block spawning migrations may be one factor responsible for the decline of blue sucker. Conversely, Pearson and Krumholz (1984) concluded that the abundance of lithophils in general (including the blue sucker) has probably declined because of degradation of spawning habitats resulting from siltation of the rock-gravel substrates. Additionally, Clay (1975) noted that the conversion of lentic to semi-lentic conditions by dams altered the preferred habitat of blue sucker and thus may be partly responsible for their decline.

Blue sucker are probably fast swimmers based on information from surrogate species and on their general habitat preferences, suggesting that they should be capable of moving upstream through mainstem dams during open river as observed for other large benthic species (e.g., lake sturgeon). Additionally, blue sucker are probably motivated to move through dams based on their life history characteristics (e.g., migratory, fluvial specialists, lithophils or litho-pelagophils). As well, based on their potential for early spawning migrations (Appendix B), blue sucker should be able to take advantage of peak open-river conditions (i.e., fish-passage opportunities) in the lower pools; however, opportunities at upper dams are minimal.

Increased abundance and distribution of other fishes (e.g., mooneye and skipjack herring) with similar life history traits and swimming abilities as blue sucker following improvements in water quality after 1970 (Pearson and Pearson 1989) suggest that re-establishment of blue suckers in the upper reaches may be possible. However, their continued absence in the upper river suggests that local populations are not sustainable in that reach and that their presence may be dependent on upstream movement through dams. Successful reintroductions in the upper reach without addressing fish passage seems unlikely given that it has not occurred yet despite water quality improvements. Conversely, spawning and feeding habitats in the upper reaches may be degraded by conversion to more lentic conditions and siltation; thus, despite fish-passage improvements, reintroductions into the upper river may fail. In the lower river where blue sucker still persist, spawning and feeding habitat must still be available, at least at some minimal level. The conversion of lotic areas to lentic or semi-lentic areas may be detrimental to fluvial specialists like blue sucker and shovelnose sturgeon that may be reliant on fast current for feeding success. These two fluvial specialists have similar distributions in that they are generally absent in the more lentic upper reaches of the Ohio River System as compared to the lower fluvial reaches. Before investing in fish-passage measures for blue sucker, more research needs to be conducted to determine the relative importance of migratory movements versus general habitat availability in sustaining their populations in the lower river.

Smallmouth, bigmouth, and black buffalo (ictiobids) are all benthopelagic macrohabitat generalists characteristic of large river systems (Smith 1979; Simon and Emery 1995; Lee et al. 1980). Smallmouth buffalo also occasionally occur in lakes, and bigmouth buffalo and black buffalo *Ictiobus nigers* are commonly found in oxbows and bottomlands marginal to large rivers (Smith 1979). Smallmouth buffalo feed on benthic invertebrates and often occupy deep clear channels with moderate to strong currents (Clay 1975; Smith 1979; Lee et al. 1980). Bigmouth and black buffalo are found in similar habitats as smallmouth buffalo but also occupy shallow turbid areas (Clay 1975; Smith 1979; Lee et al. 1980; Trautman 1981). Bigmouth buffalo are generally pelagic filter feeders, but may also feed on benthic invertebrates (Clay 1975; Smith 1979). Black buffalo have a similar feeding strategy as smallmouth buffalo (Smith 1979).

All three of these ictiobids are nonguarders and may generally spawn in backwaters or floodplain areas over vegetation and debris (phytophils or phyto-lithophils; Balon 1975; Clay 1975; Pearson and Krumholz 1984; Moyle and Cech 1988). However, others suggest that smallmouth buffalo may not be dependent on flooded or submersed vegetation for spawning. For example, Smith (1979) stated that smallmouth buffalo spawn in quiet pools or backwaters and that their eggs are "merely dropped over the bottom." As well, Clay (1975) noted that smallmouth buffalo spawn over mud bottoms and vegetation. Simon (1999) classified all three ictiobids as litho-pelagophils indicating that they spawn over rock and gravel and that their larvae are pelagic. Spawning temperature and period (Table 12), and age and size at maturity data overlap for all three species. Smallmouth buffalo have the widest reported range of spawning temperatures (i.e., 15.5 to 27°C) encompassing the range for the other two species (15.5 to 18.3°C for bigmouth buffalo and 18 to 21°C for black buffalo). All three species mature at ages 2 to 4 and at lengths of greater than 300 mm.

Little information was available on the longitudinal movements of ictiobids in large river systems as they relate to life history requirements. Bigmouth and smallmouth buffalo reportedly migrate up small tributaries to spawn in some systems (Becker 1983, Scott and Crossman 1973, Tomelleri and Eberle 1990). Lateral migrations to spawn in backwaters or on the floodplain over vegetation may be important to all three species, whereas the need for longitudinal migrations may depend on the relative location of suitable spawning sites to feeding and resting areas. As well, the movements and habitat requirements of larvae and juveniles are little known. If larvae and juveniles move downstream or upstream during maturation, then they too would need to move longitudinally to spawn and contribute to parental populations.

The prolonged and burst swimming speed estimates for all three ictiobids were 0.83 and 1.75 m/s, respectively, based on studies of the common carp (Videler 1993; Blaxter 1969). The maximum swimming speeds (U_{max}) for these species based on methods of Winter and Van Densen (2001; Equation 1) ranged from 2.34 to 3.69 m/s at median migration temperatures and 2.51 to 3.00 m/s at 15°C.

The Ohio River defines the eastern extent of the native range for all three species of buffalo fishes (Lee et al. 1980). Pearson and Pearson (1989) reported that all three species were present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River (upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). They also reported a small upstream range extension (i.e., 31 km from ORKm 87 to ORKm 56) for smallmouth buffalo since 1984. Pearson and Krumholz (1984) stated that smallmouth buffalo are probably the most abundant sucker in the Ohio River and are clearly the most abundant ictiobid. They indicated that this species is found throughout the river

but is most abundant below the mouth of the Muskingum River (ORKm 276; Belleville Pool in the upper reach). Raney (1938 in Pearson and Krumholz 1984) remarked that while Rafinesque reported that smallmouth buffalo were present as far upstream as Pittsburgh in 1820, they had not been seen there since that time. Pearson and Krumholz (1984) noted that black buffalo are the least abundant among the three species and are more common in the middle third of the river as compared to elsewhere. They also pointed out that smallmouth buffalo and black buffalo have similar distributions in the Ohio River. Conversely, bigmouth buffalo are more common in the lower Ohio River as compared to the upper river and have been documented only once above ORKm 322 (Pearson and Krumholz 1984).

Ictiobids were historically abundant in the Ohio River and its tributaries (Trautman 1981; Jordan 1882 and Henshall 1888 in Trautman 1981). However, Klippart (1878 in Trautman 1981) noted that smallmouth buffalo were formerly abundant in the Scioto River and other streams emptying into the Ohio River, but by 1878 had become less abundant. Trautman (1981) reported that between 1925 and 1950 all three species were more common in the western portion of the Ohio River in Ohio (Meldahl to Belleville Pool) as compared to the eastern portion and were only occasionally taken above the Belleville Pool. Trautman (1981) reported that the 1925 to 1950 abundance of bigmouth and black buffalo had not changed dramatically as compared to the pre-1925 levels, but indicated that fishermen claimed that smallmouth buffalo abundance declined after dams were constructed. Despite this decline, Trautman (1981) indicated that smallmouth buffalo were the most abundant ictiobid in the Ohio River during this period (i.e., 1925 to 1950), as well as in a more recent period (i.e., 1955 to 1980). Trautman (1981) indicated that the abundance of smallmouth and bigmouth buffalo in the Ohio River between 1955 and 1980 was similar to their abundance observed between 1925 and 1950; however, black buffalo abundance had apparently declined between these periods. Trautman (1981) reported the presence of bigmouth and black buffalo in the lower Muskingum River (enters Belleville Pool) and in the Scioto River, and the presence of smallmouth buffalo in the lower Scioto and Great Miami (enter Markland Pool) Rivers in the 1955 to 1980 period.

Smith (1979) found no evidence documenting temporal changes in the distribution or abundance of ictiobids in Illinois, but did suggest that smallmouth buffalo may have declined since the common carp was introduced. The species distribution maps in Smith (1979) indicated that all three species had been reported in the Wabash River, but that only smallmouth and bigmouth buffalo had been reported in the Ohio River in Illinois. Clay (1975) noted that all three species are found in the Ohio River and the lower portions of its major tributaries in Kentucky. He noted that smallmouth buffalo were more abundant in the western part of Kentucky (includes lower reach) as compared to the eastern part (includes middle reach). Clay (1975) also reported that smallmouth buffalo were the most abundant of the ictiobids followed by bigmouth buffalo and finally black buffalo. Clay (1975) indicated that all three species occurred in the Cumberland River (enters Pool 52) and that the smallmouth and bigmouth buffalo occurred in the Green River (enters Meyer Pool) and Big Sandy River (enters Greenup Pool). The smallmouth and black buffalo were found in the Rough (headwater of the Green River) and Salt Rivers (enters Cannelton Pool).

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that smallmouth buffalo were more widely distributed and generally more commonly collected than the other two species of ictiobids (Appendix B). Smallmouth buffalo were commonly collected in most pools (i.e., Smithland to Montgomery Pools) and only absent from samples taken in Dashields Pool (in the upper reach). Bigmouth buffalo were

commonly collected in the lower reach (i.e., Smithland to Newburgh Pools), occasionally collected in the middle reach (i.e., Cannelton to Meldahl Pool), and generally absent from collections in the upper reach (i.e., Greenup to Emsworth Pool; Appendix B). Black buffalo were more widely distributed than bigmouth buffalo; they were common in samples from J. T. Myers Pool (lower reach) and generally occasionally sampled from the middle reach and lower half of the upper reach (i.e., Cannelton to Pike Island Pool).

Regression analysis of the ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) indicated a significant positive trend in catch-per-unit-of-effort for smallmouth buffalo in all three sections of the Ohio River (upper—ORKm 0 to 327; middle—ORKm 327 to 1,134; and lower—ORKm 1,142 to 1,578; however, note the difference between these sections and the reaches defined by Pearson and Pearson [1989]). No significant trend was found for bigmouth buffalo in the lower and middle sections, and insufficient data from the upper section precluded an assessment. As well, black buffalo were excluded from the analysis because of insufficient data in all three sections.

Based on abundance and distribution information, smallmouth buffalo have persisted and are apparently increasing in abundance in recent times in the Ohio River despite the presence of mainstem dams. As well, an upstream range shift has recently been observed for this species (Pearson and Pearson 1989). Conversely, historical information suggests that smallmouth buffalo abundance may have declined during the 25-year period following dam construction as compared to a pre-dammed period (Trautman 1981). However, information on the abundance, distribution, and life history characteristics of smallmouth buffalo does not suggest that restricted fish passage was any more likely the cause of this decline than as, for example, was habitat degradation resulting from land-use changes or impoundment. The persistence and expansion of smallmouth buffalo in the Ohio River suggest that upstream passage through these dams is not paramount to their continued presence, rather local populations capable of sustaining the species are probably widespread in the system. Smallmouth buffalo may be benefiting from the impoundment of the system, thus explaining their apparent success in the upper reaches in recent times as compared to the pre-dammed period. Spawning habitats of smallmouth buffalo may be more general than those of bigmouth and black buffalo (Clay 1975; Smith 1979). This difference in spawning requirements may explain the apparent divergent trends among these species. However, that is not to say that smallmouth buffalo populations in the Ohio River would not benefit in terms of higher production from improved fish passage. Further research is needed to help elucidate the life history requirements of smallmouth buffalo to make an informed decision regarding the importance of longitudinal movements and upstream passage through dams.

The restricted distribution or apparent decline in abundance of bigmouth and black buffalo is suggestive that upstream fish passage may be more of a limitation for these species as compared to the smallmouth buffalo. However, to some degree, all three species were apparently limited in the upper reaches even before dams were constructed (Trautman 1981). Contrary to smallmouth buffalo, conditions conducive to the maintenance of bigmouth and black buffalo have apparently degraded in the Ohio River since dams were constructed. Whether these species are more limited by restricted fish passage or by other habitat changes brought about by anthropogenic factors, including dams, is uncertain. Scant data on the life history characteristics of these species make it difficult to assess the relative importance of these variables. For example, bigmouth and black buffalo may be more dependent on flooded vegetation and debris for reproduction as compared to smallmouth buffalo (Clay 1975; Smith 1979), thus available

spawning habitat rather than fish-passage opportunities may be the limiting factor. If longitudinal connectivity was improved by improving fish passage, bigmouth and black buffalo may have access to more spawning habitat along the river corridor.

Blue catfish are a benthic, fluvial specialists characteristic of large rivers and are typically found in deep channels or pools with fast current (Smith 1979; Lee et al. 1980; Trautman 1981; Simon and Emery 1995). Clay (1975) noted that blue catfish only occur in "larger" streams in Kentucky. Blue catfish feed in relatively fast-flowing water over nonsilt substrates and apparently avoid silt substrates in slow-flowing water (Trautman 1981). Blue catfish are omnivorous and exhibit ontogenetic shifts in diet with larger individuals (>300 mm) feeding primarily on fish (Edds et al. 2002). Abundance of blue catfish reportedly did not vary significantly among three habitat types (i.e., dam tailwaters, main channel, and tributary) in regulated rivers in Alabama, but their abundance tended to be greater over pebble-coble substrates (Grussing et al. 1999). Likewise, stock-sized blue catfish were found in similar abundance in three macrohabitat types (i.e., bendways, channels, and tailwaters) in the Tennessee-Tombigbee Waterway (Jackson 1995); however, substock-sized blue catfish were most common in channel areas. Flow and woody debris were also thought to be important for blue catfish in tailrace areas inhabited by other catfish species (Grussing et al. 1999). Blue catfish have been nearly extirpated from the reach of the Missouri River in Nebraska with probable causes listed as overharvest, reduced turbidity, and lack of large woody debris (Hesse 1994). Blue catfish are guarding spelophils (i.e., cavity nester), presumably nesting along banks of rivers and connected backwaters. We found no information on age at maturity for blue catfish. However, Perry and Carver (1977) reported a computed length at maturity for blue catfish of 481 mm in marshes of southwest Louisiana. As well, Pflieger (1975) reported that adult fish are commonly 508 to 1,117 mm and 1.4 to 18.2 kg. Reported spawning temperatures for blue catfish ranged from 21 to 24°C (Harlan and Speaker 1956).

Little information was available on the migratory behaviors of blue catfish, although Coker (1930 in Smith 1979) indicated that the Keokuk Dam on the Upper Mississippi River blocked their upstream migration and that all reports of blue catfish in that region were from summer months. As well, Welter (1938 in Clay 1975) noted that blue catfish were common in the Licking River (enters Markland Pool; middle reach of the Ohio River) at Farmers, Kentucky, in spring, suggesting a migration of considerable distance if one assumes they originated from preferred habitats in the Ohio River; the straight-line distance from the Ohio River to Farmers is about 145 km.

The estimate for prolonged swimming speed for blue catfish was 0.71 m/s based on a study of channel catfish (Tunink 1975). No information was available on observed or modeled burst speed for blue catfish or any other morphologically similar species. However, maximum speeds of median-sized adult blue catfish estimated with methods of Winter and Van Densen (2001; Equation 1) were 5.74 m/s at a median migration temperature of 20°C and 4.10 m/s at 15°C. As well, the flattened head of blue catfish may provide them a mechanism to hold position in high water velocities (i.e., substrate appression), allowing them to alternate between resting and bursting to pass upstream through dams.

The upper Ohio River represents the eastern extent of the native distribution for blue catfish, with populations occurring to the north and south in the Mississippi River System (Lee et al. 1980). Pearson and Pearson (1989) reported that blue catfish were present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River

(i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). They also reported that blue catfish abundance increased between 1980 and 1988 in the lower two reaches of the Ohio River, replacing bullheads on the top-10 list of abundant species in ORSANCO lock rotenone samples. Pearson and Krumholz (1984) noted the presence of blue catfish in the Ohio River from the mouth to ORKm 89 (New Cumberland Dam); however, blue catfish were rare in the upper reach and abundance increased going downstream from Pittsburgh. Pearson and Krumholz (1984) also reported that no notable change in the distribution of blue catfish had occurred since 1970, but that abundance was declining in the upper half of the river.

Trautman (1981) concluded that blue catfish were present in the Ohio River in Ohio between the Indiana state line and Belmont County (i.e., middle and upper reaches including Markland to Hannibal Pool) before 1900. He also noted that blue catfish were reportedly more common in the river before impoundment (pre-1911) as compared to after impoundment. Trautman (1981) reported that between 1925 and 1950, he examined more than 20 blue catfish taken from the Indiana state line to Portsmouth, Ohio (Markland to Meldahl Pool; upper half of the middle reach). However, based on reports from 1955 to 1980, blue catfish had become less abundant in the middle and upper reaches of the Ohio River in Ohio as compared to earlier periods (Trautman 1981).

Clay (1975) stated that blue catfish were most abundant in the lower reach of the Ohio River, uncommon between Louisville, Kentucky, and Cincinnati, Ohio (i.e., the lower half of the middle reach), and rare or absent in the upper reach. He also noted that blue catfish occur in the lower reaches of large tributaries to the Ohio River. Interestingly, Clay (1975) did not cite any reports of blue catfish occurring above dams on these large tributaries in Kentucky. Distribution maps in Smith (1979) indicate that blue catfish have been reported in the lower reach of the Wabash River in Illinois.

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that blue catfish were generally commonly collected from the lower reach (i.e., ORKm 1,053 to 1,578) of the Ohio River, uncommon in the middle reach (ORKm 527 to 1,052), and absent from the upper reach (i.e., ORKm 0 to 526; Appendix B). Regression analysis of the ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) indicated a significant positive trend in catch-per-unit-of-effort for blue catfish in the lower section of the Ohio River (ORKm 1,142 to 1,578) and a significant negative trend in the middle section (ORKm 327 to 1,134; however, note the difference between these sections and the reaches defined by Pearson and Pearson [1989]). Insufficient data were available from the upper section (above ORKm 327) to make a trend assessment.

The present abundance and distribution of blue catfish are such that they may be related to fish-passage opportunities. Blue catfish are absent in upper reaches where few or no passage opportunities exist and abundance increases with increasing fish-passage opportunities in the lower reaches. As suggested by their habitat preference for channels with swift currents, relatively high maximum swimming speeds, and flattened head, blue catfish may be able to pass upstream through open dams in the lower and middle reaches of the Ohio River. However, no species-specific swimming speed information or empirical fish-passage data were available for blue catfish, thus leaving some uncertainty as to their capability. The relatively late spawning migration period of blue catfish based on reported spawning temperatures (Appendix B) suggests that they may miss the peak period of open river and thus be more longitudinally restricted than

first seems apparent. As well, little information was available on their migratory behavior, thus leaving uncertainty as to their propensity to move upstream to spawn.

As suggested by the southern nature of their native range (Lee et al. 1980), blue catfish may also be thermally limited and thus restricted to the lower reaches of the Ohio River during winter; their presence in the upper reaches may be dependent on upstream passage during spring or summer. In the Upper Mississippi River, blue catfish were apparently present as far north as Lock and Dam 19 (roughly equivalent latitude as Pittsburgh, Pennsylvania) only after migrations from further south (Coker 1930 in Smith 1979). This suggests that the presence of blue catfish in the middle and particularly in the upper reaches of the Ohio River may also have been a seasonal phenomenon with fish migrating upstream during spring to spawn and returning to the lower reaches in summer or fall to feed and overwinter. However with upstream passage restrictions at upper reach dams, blue catfish may be limited to the lower reaches even during spring and summer.

In addition to fish-passage opportunities and climate, habitat preference probably influences the present distribution of blue catfish in the Ohio River that is now heavily silted and slow-moving in some reaches because of impoundment. The lower reach of the Ohio River may be more similar to blue catfish native habitat (i.e., large rivers with deep pools, substantial current, and nonsilt substrates) as compared to the more lentic and silt-laden upper and middle reaches. To increase the chances of success, restoration efforts for blue catfish populations in the middle and particularly upper reaches of the Ohio River would need to consider habitat requirements as well as fish-passage needs. Managers should also consider that restoration efforts in the upper reach may always be limited by physical habitat characteristics and climate.

White bass, yellow bass, striped bass, and white perch (moronids) are generally considered fluvial-dependent species characteristic of large river systems during at least part of their life cycle (Lee et al. 1980; Simon and Emery 1995; Galat and Zweimüller 2001). White and yellow bass are native to the Ohio River Basin, whereas striped bass and white perch *Morone americana* are naturally anadromous or semi-anadromous species with native distributions extending along the East Coast of North America. Both of these anadromous species have been widely introduced and in some instances have become established in inland systems (Lee et al. 1980; USGS 2003). Adult white bass feed primarily on fish, but also on invertebrates (Smith 1979; Hartman 1998) and generally occupy the pelagic zone of open-water habitats; however, they do move inshore to exploit food resources (Beck and Willis 2000). Conversely, yellow bass and white perch generally prefer more lentic habitats and feed on fish and benthic invertebrates and seasonally on fish eggs (Clay 1975; Smith 1979; Trautman 1981; Driscoll and Miranda 1999; USGS 2003). Adult striped bass in inland systems probably have similar food habits and habitat preferences as white bass.

White bass generally spawn over submerged vegetation or firm bottom substrates in flowing water and eggs attach to the substrate (i.e., nonguarder, phyto-lithophil). Yellow bass may have similar spawning ecology as that of white bass (Smith 1979); however, in contrast to other moronids, yellow bass may be less dependent on flowing water to reproduce and may pair during spawning (Texas Parks and Wildlife 2003). Striped bass also spawn over firm substrates in flowing water but their eggs drift until hatching (i.e., nonguarder, litho-pelagophil; Beasley and Hightower 2000; Maryland Department of Natural Resources [MDNR] 2003). Conversely, Simon (1999) indicates that striped bass have a similar reproductive strategy as other moronids (i.e., phyto-lithophil) with nonpelagic larvae. White perch may be more flexible in their

spawning behavior as compared to white and yellow bass, exhibiting characteristics of either phyto-lithophils or litho-pelagophils depending on whether the system they occupy is lentic or lotic (MDNR 2003). All of these moronids spawn in the spring, but variation exists among the species as to the reported spawning temperatures (Table 12). Males of all four species mature at age 2 to 3; females of the smaller moronids (i.e., white perch, white bass, and yellow bass) mature at age 3 to 4, whereas striped bass females generally mature at age 4 to 6 (Becker 1983; Stauffer et al. 1994; MDNR 2003).

All four species are known to migrate upstream in rivers, streams, or reservoirs to spawn. Schools of white bass are reported to home to shoals in lakes or move into streams to spawn (Lee et al. 1980; Becker 1983). As well, white bass were highly mobile during a tagging study in the Upper Mississippi River (Finke 1966 in Becker 1983); the average distance traveled between captures by 57 tagged fish during that study was 34 km. As well, these white bass congregated in the tailwaters of Lock and Dam 3 in the spring and in some instances moved upstream through that dam and into a major tributary (Finke 1966 in Becker 1983). Similarly, yellow bass congregate in tailwaters of dams that block their migrations and move into tributaries to spawn (Carter 1955 in Clay 1975; Becker 1983). White perch and striped bass in their native range generally migrate in fall or late winter-early spring from coastal areas up large rivers and streams to spawn (Lee et al. 1980; Tomelleri and Eberle 1990; MDNR 2003). Striped bass historically migrated up to 435 km in a river in North Carolina (Beasley and Hightower 2000). In an inland reservoir in Texas (i.e., Lake Whitney), adult striped bass moved upstream and into main tributaries to overwinter before returning to the reservoir in spring (Farquhar and Gutreuter 1989). White perch from Green Bay in Lake Michigan migrated up the Fox River, Wisconsin, to the tailwaters of a dam possibly to spawn (Cochran and Hesse 1994).

The prolonged swimming speed of white bass was estimated at 0.78 m/s based on observations of that species (Tunink 1975). This value was also used as an estimate of the prolonged swimming speed of yellow bass and white perch as no species-specific information was available. The estimated prolonged swimming speed (in this instance U_{crit30} rather than U_{crit10}) of striped bass was 0.86 m/s based on work by Freadman (1981). The estimated range of burst speeds for white and striped bass, based on a study of American shad, was 3.47 to 4.15 m/s (Weaver 1965). Maximum swimming speeds (U_{max}) as determined by the methods of Winter and Van Densen (2001; Equation 1) were 4.05 to 4.66 m/s for white bass, 3.56 to 3.81 m/s for yellow bass, 3.52 to 4.69 m/s for striped bass, and 1.69 to 2.22 m/s for white perch.

The upper Ohio River is the eastern extent of the native range for white bass at that latitude. However, the native range of white bass extends to the northeast in the Great Lakes Basin, and transplanted populations occur to the southeast (Lee et al. 1980). In the summary by Pearson and Pearson (1989), white bass were the only representative of the moronids present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). Pearson and Krumholz (1984) indicated that white bass were most common below ORKm 483 and suggested that their abundance may be increasing in the middle reach of the river possibly because of reduced turbidity.

Trautman (1981) cited Jordan (1882) as having considered the white bass to be uncommon in the Ohio River drainage before impoundment. However, Kirkland (1850 in Trautman 1981) indicated that white bass were very common in the Mahoning River (a tributary of the Beaver River that enters the Ohio River in Montgomery Pool) in 1810. Trautman (1981) also stated that white bass were quite uncommon in the Ohio River from 1920 to 1950

(presumably in the state of Ohio) and that they were found only as far upstream as Lawrence County (Greenup Pool). He also noted that the species was uncommon in the lower Scioto River (enters upper Meldahl Pool) and nearly absent from other streams including the Muskingum River (enters Belleville Pool). White bass had been introduced into many inland impoundments and streams in Ohio since the turn of the 20th century (Trautman 1981). However, before 1955 they had become established in only the larger clear impoundments in Ohio rather than the smaller more turbid ones. Between 1968 and 1969, H. Ronald Preston (in Trautman 1981) reported that white bass were present near dams in the Ohio River between Meigs and Clermont counties (Markland to Racine Pool; middle and lower portions of the upper reach). The species distribution map in Smith (1979) indicates that white bass were present in the Ohio River along the border of Illinois and also in the Wabash River. Clay (1975) reported that white bass occurred throughout the state of Kentucky in medium to large streams and reservoirs including the Big Sandy River (enters Greenup Pool).

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that white bass were commonly collected throughout the length of the Ohio River, with the exception of Emsworth Pool where they were occasionally collected (Appendix B). In an analysis of the ORSANCO lock rotenone data (1957 to 1997), Lowman (2000) found that the abundance of the white bass indicated a few peak years in the late 1980s and early 1990s with a recent return to relatively low levels. Data from all three sections of the Ohio River (upper—ORKm 0 to 327; middle—ORKm 327 to 1,134; and lower—ORKm 1,142 to 1,578; however, note the difference between these sections and the reaches defined by Pearson and Pearson [1989]) were combined for this analysis.

With the exception of a few introduced populations and populations in the Tennessee River, the lower Ohio River is the eastern extent of the native range for yellow bass, but central to its latitudinal distribution (Lee et al. 1980). Pearson and Pearson (1989) reported that yellow bass were originally present (before 1970) in just the lower reach (ORKm 1,053 to 1,578) of the Ohio River, and recently present (1970 to 1988) in the lower and middle reaches from ORKm 527 to 1,052; this suggested a recent range extension or possibly just improved sampling efficiency (e.g., electrofishing) or increased effort. Jordan (1882 in Pearson and Krumholz 1984) indicated that yellow bass were present in the Ohio River from the mouth upstream to at least the confluence with the Wabash River (enters upper Smithland Pool). Pearson and Krumholz (1984) stated that yellow bass were restricted to the lower half of the Ohio River and were encountered most often in the lower 161 km (i.e., the mouth to the middle of Smithland Pool). As well, Clay (1975) noted that yellow bass were generally restricted to large streams and reservoirs in western Kentucky including those in the Tennessee and Cumberland Rivers (both enter Pool 52). Where they occur in Kentucky, yellow bass are much less abundant than white bass (Clay 1975). However, Clay (1975) believed that the impoundment of large streams may have resulted in increased abundance of yellow bass. Smith (1979) stated that yellow bass are generally rare in the Ohio and Wabash (enters Smithland Pool) Rivers and indicated that high turbidities in some Illinois lakes may have contributed to their general decline. Trautman (1981) makes no reference to yellow bass, probably because they generally do not occur in Ohio waters, including the Ohio River.

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that yellow bass were commonly collected in Smithland Pool, occasionally collected in J. T. Myers Pool and uncommonly collected in Meldahl Pool; this species was absent from samples taken in the remaining pools (Appendix B). The occurrence of

yellow bass in the Meldahl Pool is aberrant given its absence from samples in the four pools between Meldahl and J. T. Myers Pool. Analysis of ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) suggested that yellow bass abundance is increasing when data for the entire river are combined; however, the data were insufficient for making conclusions with respect to individual sections.

White perch occur broadly in estuaries and coastal ponds and lakes in their native range along the East Coast of North America (Lee et al. 1980). Trautman (1981) indicated that white perch had been introduced into Lake Erie, but made no mention of them in the Ohio River. He also noted that, in its native range, this species prefers clear waters with low gradients and also noted that white perch often become abundant in areas where they have been introduced. White perch have been introduced into as many as 18 states according to the U.S. Geological Survey's Nonindigenous Aquatic Species Database (USGS 2003); however, this database does not indicate the occurrence of white perch in the Ohio River despite their recent capture (i.e., 1993 to 2000) in the upper reach of that system. In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that white perch were sampled occasionally in R. C. Byrd and Racine Pools and uncommonly in Pike Island Pool (upper reach; Appendix B). The occurrence of white perch in Pike Island Pool is aberrant given its absence from samples taken in the three pools between Pike Island Pool and Racine Pool.

The Ohio River is not within the native range of the striped bass; however, this species has been widely introduced into the basin (Lee et al. 1980). Pearson and Pearson (1989) found that striped bass were present during a recent period (1970 to 1988) in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578), but absent from samples taken before 1970. They also indicated that striped bass abundance may be increasing, but were uncertain as to whether this increase was the result of stocking or natural reproduction. Pearson and Pearson (1989) also documented an upstream range extension for this species since 1983 with the upper limit moving from ORKm 203 to ORKm 21. Pearson and Krumholz (1984) stated that striped bass have been stocked in the Ohio River since 1967, and that beginning in 1975 they had been found from Pool 52 to the Falls of the Ohio (i.e., in the lower reach). According to Trautman (1981), stocking took place in 1968 with the release of fry into various reservoirs and other waters in the Ohio River drainage, including the Little Muskingum River (enters Belleville Pool), but with discouraging results. Smith (1979) reported that striped bass were first recorded in Illinois' portion of the Ohio River in 1974 and presumed that this fish was the result of stocking in impoundments in western Kentucky. Clay (1975) documented that as early as 1957 striped bass were stocked in impoundments within the drainages of the Cumberland (enters Pool 52), Green (enters J. T. Myers Pool), Kentucky (enters McAlpine Pool), and Big Sandy (enters Greenup Pool) Rivers. Clay (1975) also stated that successful spawning probably was not occurring in Kentucky, but that stocking could maintain the fishery.

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that striped bass were generally commonly sampled in the lower (i.e., ORKm 1,053 to 1,578) and middle (i.e., ORKm 527 to 1,052) reaches and occasionally sampled in the upper reach (i.e., ORKm 0 to 526; Appendix B). The species was not sampled in Pike Island Pool or in the uppermost three pools (i.e., Montgomery, Dashields, and Emsworth Pools; Appendix B). Analysis of ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) did not reveal any significant trends in the abundance of striped bass in the Ohio River.

Swimming abilities and behaviors (e.g., pelagic or benthopelagic, and migratory) suggest that white, yellow, and striped bass are probably capable and motivated to move upstream through open dams on the Ohio River. White bass, yellow bass, and white perch are known to occupy tailwaters, particularly in spring (Carter 1955 in Clay 1975; Finke 1966 in Becker 1983; Cochran and Hesse 1994). White bass are known to move upstream through navigation dams on the Upper Mississippi River during spring (Finke 1966 in Becker 1983). White perch are probably similarly motivated as the other moronids to move upstream base on their anadromous life history, but may be more limited in ability because of their smaller size and estimated lower swimming speed (Table 8). Likewise, white and yellow bass may be somewhat more restricted than striped bass. Based on their relatively early spring migration periods, moronids should encounter open dams in the lower reach of the Ohio River relatively often with decreasing frequency going upstream (Appendix B).

With the potential exception of white perch, passage restrictions imposed by dams do not seem to be affecting the distribution or abundance of moronids. White, yellow, and striped bass seem to be expanding their distributions, and potentially increasing in abundance since completion of the mainstem dams. These trends probably are the result of improved conditions for these species in terms of reduced turbidities and pollutants (Clay 1975; Pearson and Pearson 1989). As well, ongoing stocking programs for white and striped bass may be contributing to their apparent success. The success of white perch is probably not dependent on fish-passage opportunities given their apparent success in lentic systems elsewhere (Lee et al. 1980; USGS 2003). If other environmental factors are not limiting, white perch may eventually spread throughout the system. However, given their apparent limited distribution (i.e., generally two pools in the lower portion of the upper reach) and that they were introduced into the Ohio River as early as 1993, white perch may be limited by other factors.

Walleye and sauger *(Stizostedion* species*)* are benthopelagic indicating that they can be found near the bottom or suspended in the water column. Walleye and sauger have been classified as macrohabitat generalists (T. Koel, National Park Service, Yellowstone National Park, Wyoming, unpublished data); however, sauger may be fluvial dependent (Clay 1975; Lee et al. 1980; Trautman 1981). Nelson (1968 in Lee et al. 1980) noted that sauger reproduction and survival of young may be dependent on large river habitats. Both species are piscivores that can be found in rivers or lakes; however, walleye are less tolerant of turbidity and silt as compared to sauger (Clay 1975; Lee et al. 1980; Trautman 1981). Walleye and sauger in the Upper Mississippi River prefer flowing-water habitats including main and side channels and tailwaters of dams (Becker 1983). Both species are known to spawn in rivers and lakes (Clay 1975; Becker 1983), but walleye may be more generalists when selecting spawning sites than are sauger, as walleye also use backwater areas and flooded wetlands to spawn (Clay 1975; Smith 1979; Becker 1983). As well, both species generally spawn over gravel or rock bottoms, and eggs initially adhere to the substrate but become buoyant and drift upon hardening (i.e., nonguarder, litho-pelagophils; Simon 1999). Male sauger reached sexual maturity at age 2, whereas females mature at age 3 or 4 (Becker 1983). Male walleye mature at age 2 to 5, whereas females mature at age 4 to 8.

In spring, both species make migrations up rivers and tributaries to spawn, which reportedly occurs at water temperatures of about 4 to 11°C for sauger and 6 to 11°C for walleye (Scott and Crossman 1973). Collette et al. (1977 in Becker 1983) noted that sauger were the most migratory of the percids and moved up to 380 km during one tagging study. Walleye and sauger moved up to 63 km and 57 km, respectively, away from tagging sites in the Mississippi

River, but in general movement out of the navigation pool they were tagged in was not significant (Hubley 1963 in Becker 1983). Hubley (1963 in Becker 1983) also indicated that dams did not prohibit walleye and sauger movements between navigation pools. In the Tennessee River, radio-tagged sauger concentrated in the tailwater area of the Pickwick Dam in fall and winter (Pegg et al. 1997) and then after the presumed spawning period migrated downstream up to 200 km into Kentucky Lake. During that study, four radio-tagged sauger moved upstream through the locks of Pickwick Dam (Pegg et al. 1997). Clay (1975) noted that walleye and sauger are potadromous and that one tagged sauger reportedly moved upstream 385 km in the Tennessee River. Walleye also move considerable distances into rivers to spawn. For example, in Lake Winnebago, Wisconsin, walleye moved up to 123 km into the Fox River during the spawning season (Becker 1983).

Two studies (Jones et al. 1974; Tunink 1975) found that the prolonged swimming speed of walleye was 0.80 m/s (Table 8). The observed prolonged swimming speed of sauger was 0.60 m/s (Tunink 1975). The estimated burst swimming speeds of adult-sized walleye and sauger were 2.20 and 2.14 m/s, respectively, based on a study of walleye (Peake et al. 2000). The maximum swimming speeds (U_{max}) as determined by the methods of Winter and Van Densen (2001; Equation 1) were 2.67 to 4.30 m/s for walleye and 2.36 to 4.14 m/s for sauger (Table 8).

The Ohio River Basin defines the southern and eastern (at that latitude) extent of the native range for walleye and sauger (Lee et al. 1980). Pearson and Pearson (1989) found that walleye and sauger were present during an early (1800 to 1969) and recent (1970 to 1988) period in all three reaches of the Ohio River (i.e., upper—ORKm 0 to 526; middle—ORKm 527 to 1,052; and lower—ORKm 1,053 to 1,578). Pearson and Krumholz (1984) reported that sauger were common throughout the Ohio River and indicated that they were more abundant after 1970, particularly in the middle reach. They also noted that sauger were taken only occasionally in the upper 322 km before 1970, but had since increased in abundance in that reach. Conversely, they believed that walleye populations were declining. However, in an update of the work done by Pearson and Krumholtz (1984), Pearson and Pearson (1989) indicated that populations of walleye and sauger had increased in the last 20 years.

The distribution of walleye and sauger before 1850 is unclear because early accounts considered these fishes as a single species (Trautman 1981). Henshaw (1888 in Trautman 1981) indicated that walleye and sauger were common in the Ohio River in 1887. Trautman (1981) stated that the larger and less turbid streams in Ohio contained abundant walleye before 1900, but that after that time a decrease was apparent. Kirtland (1850 in Trautman 1981) noted a decrease in the abundance of walleye in the Mahoning River (enters Beaver River that enters Montgomery Pool) following the construction of a dam on that river. As well, Klippart (1874 in Trautman 1981) noted a decline in the abundance of walleye and sauger from once abundant to rare on the Scioto River (enters Meldahl Pool) following the construction of the State Dam a few miles downstream from Chillicothe. Trautman (1981) noted that after 1940 walleye rarely occurred in the Scioto River; however, recently fishing for walleye had been fair possibly because of stocking programs in upstream reservoirs. On the Ohio River, accounts indicated that walleye were less abundant after dams were constructed (about 1911) as compared to before (Trautman 1981). Smith (1979) reported that walleye and sauger are sporadic in Illinois, but that sauger were probably more common than reports indicated. Clay (1975) noted that walleye were present in all major drainages in Kentucky, however, early reports may be erroneous given that these reports did not always make distinctions between the two species.

Hubbs and Lager (1947 in Trautman 1981) indicated that sauger were present in the Ohio River drainage including the Tennessee River System before settlement by the Europeans. Trautman (1981) stated that from 1925 to 1950 sauger were fairly numerous from the Indiana state line (Markland Pool) to Washington County (Belleville and Willow Island Pools in the upper reach of Ohio River) and in the Scioto River (enters Meldahl Pool) upstream to Pickaway County. Trautman (1981) noted that sauger were considerably less abundant in the Muskingum River (enters Belleville Pool) as compared to the Scioto River between 1925 and 1950. Trautman (1981) also noted that the abundance of inland sauger was never high and remained relatively constant between 1950 and 1980; however, they were broadly distributed in the Ohio River in Ohio during this period. Clay (1975) stated that sauger were found in all rivers of Kentucky and noted their preference for rivers and impoundments, but not small streams.

In an analysis of recent data (1989 to 2001; ORSANCO unpublished data; OEPA unpublished data), we found that walleye were generally collected occasionally to commonly in the lower reach (i.e., ORKm1,053 to 1,578), occasionally in the middle reach (i.e., ORKm 527 to 1,052), and commonly in the upper reach (i.e., ORKm 0 to 526; Appendix B). Sauger were commonly collected in all three reaches of the Ohio River (Appendix B). Analysis of the ORSANCO lock rotenone data (1957 to 1997) by Lowman (2000) indicated that walleye were increasing in all three sections of the Ohio River (upper—ORKm 0 to 327; middle—ORKm 327 to 1,134; and lower—ORKm 1,142 to 1,578; however, note the difference between these sections and the reaches defined by Pearson and Pearson [1989]) and that sauger were increasing in the upper and middle sections, but not in the lower section.

Life history and swimming performance information for walleye and sauger suggest they are probably capable and motivated to move upstream through open mainstem dams (Table 8). Both species are known to move upstream through navigation dams on the Upper Mississippi or Ohio Rivers (Hubley 1968 in Becker 1983; Holland et al. 1984; C. O'Bara, West Virginia Department of Natural Resources, Parkersburg, West Virginia, personal communications). Walleye and sauger are benthopelagic suggesting that they may be able to take advantage of the lowest water velocities in the upper portion of the gate openings to move upstream through dams. Their early spring spawning period suggests that they could take advantage of the open river period at lower and middle reach dams (Appendix B). As well, sauger occupy tailwater areas during other seasons (Pegg et al. 1997) and thus may pass upstream through open dams at times other than spring.

The abundance and distribution information for walleye and sauger suggest that they are not dependent on movement through dams to be successful in the Ohio River. Rather local (within pool) or upstream populations are apparently responsible for their broad distribution and abundant status. Despite an apparent initial declined in abundance following dam construction in the Ohio River and associated tributaries, walleye and sauger appear to be increasing in abundance and distribution recently, particularly in the upper and middle reaches (Pearson and Pearson 1989; Lowman 2000). Pearson and Pearson (1989) suggest this expansion in abundance and distribution is related to improvements in water quality. Others have noted that stocking programs may play a role in recent increases in abundance in tributaries (Trautman 1981); this may also be a factor in the Ohio River mainstem. Whether the initial decline was related to factors other than lack of upstream fish passage (e.g., turbidity or pollution) is uncertain given the qualitative nature of the historic information and the concurrent nature of these stressors. Likewise, present abundance may still be lower than pre-dam abundance but information on historical abundance and controlling factors are uncertain. More system-specific research is

needed on the factors that influence the population dynamics of *Stizostedion* species to help ascertain if the lack of upstream passage at mainstem dams affects their production potential in the Ohio River and its major tributaries.

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Table 1. A list of the common and scientific names of the 44 target fish species used in the assessment of fish passage opportunities at Ohio River mainstem dams.

Common Name	Scientific Name
Lake sturgeon	*Acipenser fulvescens*
Shovelnose sturgeon	*Scaphirhynchus platorynchus*
Paddlefish	*Polyodon spathula*
Longnose gar	*Lepisosteus osseus*
Shortnose gar	*L. platostomus*
Goldeye	*Hiodon alosoides*
Mooneye	*H. tergisus*
American eel	*Anguilla rostrata*
Alabama shad	*Alosa alabamae*
Skipjack herring	*A. chrysochloris*
Alewife	*A. pseudoharengus*
Goldfish	*Carassius auratus*
Grass carp	*Ctenopharyngodon idella*
Common carp	*Cyprinus carpio*
Silver carp	*Hypophthalmichthys molitrix*
Bighead carp	*H. nobilis*
River carpsucker	*Carpiodes carpio*
Quillback	*C. cyprinus*
Highfin carpsucker	*C. velifer*
White sucker	*Catostomus commersoni*
Blue sucker	*Cycleptus elongates*
Smallmouth buffalo	*Ictiobus bubalus*
Bigmouth buffalo	*I. cyprinellus*
Black buffalo	*I. niger*
Spotted sucker	*Minytrema melanops*
Silver redhorse	*Moxostoma anisurum*
River redhorse	*M. carinatum*
Black redhorse	*M. duquesnei*
Golden redhorse	*M. erythrurum*
Shorthead redhorse	*M. macrolepidotum*
White catfish	*Ameiurus catus*
Blue catfish	*Ictalurus furcatus*
Channel catfish	*I. punctatus*
Northern pike	*Esox lucius*
Muskellunge	*E. masquinongy*
White perch	*Morone americana*
White bass	*M. chrysops*
Yellow bass	*M. mississippiensis*
Striped bass	*M. saxatilis*
Smallmouth bass	*Micropterus dolomieu*
Largemouth bass	*M. salmoides*
Sauger	*Stizostedion canadense*
Walleye	*S. vitreum*
Freshwater drum	*Aplodinotus grunniens*

Table 2. Channel and floodplain width, stream gradient, and mean annual discharge at or between various locations along the Ohio River mainstem. *Data from Pearson (1992). **Gradient estimated from Figure 1 between ORKm 0 and 496, ORKm 496 and 1,274, and ORKm 1,274 and 1,578. Ohio River Kilometer (ORKm) is measured from the source of the Ohio River at the confluence of the Allegany and Monongahela Rivers.

Point (ORKm)	Channel* width (m)	Floodplain* width (m)	Channel substrate elevation (m)	Gradient** (m/km)	Discharge* (m^3/s)
Source (0)	366	1,300	689	-	906
Middle (496)	460	-	480	0.13	2,210
Middle (1,274)	550	-	325	0.06	3,796
Mouth (1,578)	1,097	11,000	250	0.08	7,307

Table 3a. Characteristics of the Ohio River mainstem dams and navigation pools in the Louisville District.

Dam	Dam 53	Dam 52	Smithland	J. T. Myers	Newburgh	Cannelton	McAlpine	Markland
Type	movable wicket dam, navigable pass	movable wicket dam, navigable pass	gated-dam, navigable fixed-weir	gated-dam, navigable fixed-weir	gated-dam, navigable fixed-weir	gated-dam, fixed-weir	gated-dam	gated-dam
River kilometer	1,549.1	1,511.0	1,478.1	1,361.5	1,249.0	1,160.0	976.5	855.3
Pool length (km)	36.5	33.0	116.7	112.5	89.2	183.5	121.2	153.4
Number of major tributaries[a]	0	2	1	1	0	1	1	2
Normal pool elevation (m)	88.4	92.0	98.8	104.2	109.1	116.7	128.0	138.7
Normal lift across dam (m)	4.1	3.7	6.7	6.7	4.9	7.6	11.3	10.7
Year open	1929	1928	1980	1975	1975	1972	1961	1963
Total dam span (m)[b]	1,230	1,023	994	1,159	835	522	850[c]	608
Total sill length (m)[d]	---	---	---	---	---	---	---	---
Fixed weir spillway width (m)	1085	914	479	682	396	59	---	---
Gated spillway width (m)	---	---	424	386	348	371	324	425
Number of gates	---	---	11	10	9	12	9	12
Type of gates	---	---	tainter	tainter	tainter	tainter	tainter	tainter
Hydropower (Y or N)	N	N	N	N	N	N	Y	Y
Major modifications	1974: addition of temporary main lock	1969: addition of temporary main lock	---	---	---	---	---	---

[a]Tributaries with annual mean discharges $\geq$28.3 m^3/s.
[b]Total span of structure from land wall to abutment... includes locks, dam, and hydropower.
[c]Only includes sections perpendicular to channel; excludes fixed weir and gated section parallel to channel.
[d]Combined length of sill and stilling basin for gated sections.

Table 3b. Characteristics of the Ohio River mainstem dams and navigation pools in the Huntington District.

Dam	Meldahl	Greenup	R. C. Byrd	Racine	Belleville	Willow Island
Type	gated dam, fixed-weir	gated-dam, fixed-weir	gated-dam	gated-dam	gated-dam, fixed-weir	gated-dam, fixed-weir
River kilometer	702.0	548.8	449.3	382.2	328.1	260.2
Pool length (km)	153.2	99.5	71.8	54.1	67.9	56.8
Number of major tributaries[a]	1	2	1	---	2	---
Normal pool elevation (m)	147.8	157.0	164.0	170.7	177.4	183.5
Normal lift across dam (m)	9.1	9.1	7.0	6.7	6.7	6.1
Year open	1964	1962	1937	1967	1965	1972
Total dam span (m)[b]	626	482	434	408	465	435
Total sill length (m)[c]	39	38	51	40	44	38
Fixed weir spillway width (m)	113	75	---	---	58	34
Gated spillway width (m)	422	318	345	310	310	310
Number of gates	12	9	8	8	8	8
Type of gates	tainter	tainter	roller	tainter	tainter	tainter
Hydropower (Y or N)	N	Y	N	Y	N	N
Major modifications		1982: addition of hydropower		1983: addition of hydropower		
Additional comments	fixed weir with 95 m open crest	fixed weir with 68 m open crest			fixed weir with 40 m open crest	fixed weir with 26 m open crest

[a]Tributaries with annual mean discharges $\geq$28.3 m^3/s.
[b]Total span of structure from land wall to abutment... includes locks, dam, and hydropower.
[c]Combined length of sill and stilling basin for gated sections.

Table 3c. Characteristics of the Ohio River mainstem dams and navigation pools in the Pittsburgh District.

Dam	Hannibal	Pike Island	New Cumberland	Montgomery	Dashields	Emsworth
Type	gated-dam, fixed weir	gated-dam, fixed-weir	gated-dam	gated-dam, fixed-weir	fixed-weir	gated-dam, fixed-weir
River kilometer	203.4	135.5	87.5	51.0	21.4	10.0
Pool length (km)	67.9	48.0	36.5	29.6	11.4	38.8
Number of major tributaries[a]	0	0	0	1	0	2[b]
Normal pool elevation (m)	189.9	196.3	202.5	207.9	210.9	216.4
Normal lift (m)	6.1	6.4	6.2	5.3	3.0	5.5
Year open	1972	1963	1959	1936	1929	1921
Total dam span (m)[c]	518	487	490	486	549	361
Total sill length (m)[d]	41	35	31	36	---	31
Fixed weir spillway width (m)	24	60	---	67	483	11
Gated spillway width (m)	311	338	401	354	---	513[e]
Number of gates	8	9	11	10	---	14[e]
Type of gates	tainter	tainter	tainter	Sidney	---	Sidney
Hydropower (Y or N)	Y	N	N	N	N	N
Major modifications	1988: addition of hydropower shortened fixed weir from 34 m to 24 m					1938: converted to gated structure, raising pool an additional 2.1 m

[a]Tributaries with annual mean discharges $\geq$28.3 m^3/s.
[b]Allegheny and Monongahela rivers.
[c]Total span of structure from land wall to abutment... includes locks, dam, and hydropower.
[d]Combined length of sill and stilling basin for gated sections.
[e]284 m, 8-gated main channel dam, plus 229 m, 6-gated back channel dam

Table 4. Tributaries of the Ohio River with mean annual discharge rates at the gaging station nearest the Ohio River =28.3 m³/s. Raw data was from the U.S. Geological Survey's real-time water data Web site, http://waterdata.usgs.gov/.

Tributary	Enters Ohio River at river km	Enters Ohio River at navigation pool	Gaging station location			Mean of annual mean stream flow in m^3/s at station	Minimum of annual mean stream flow in m^3/s at station	Maximum of annual mean stream flow in m^3/s at station
			Latitude	Longitude	Nearest city			
Allegheny River (PA)	0.0	Emsworth	40`36'55"	79`43'07"	Natrona, PA	556	346	815
Monongahela River (PA)	0.0	Emsworth	40`23'28"	79`51'30"	Braddock, PA	355	234	597
Beaver River (PA)	40.6	Montgomery	40`53'19"	80`20'14"	Wampum, PA	72	27	127
Muskingum River (OH)	275.5	Belleville	39`38'42"	81`51'00"	McConnelsville, OH	217	78	360
Little Kanawha River (WV)	295.4	Belleville	39`03'32"	81`23'23"	Palestine, WV	61	28	102
Kanawha River (WV)	425.1	Byrd	38`22'17"	81`42'08"	Charleston, WV	429	232	680
Guyandotte River (WV)	488.3	Greenup	37`50'32"	81`58'34"	Logan, WV	33	14	57
Big Sandy River (WV-KY)	507.4	Greenup	38`10'16"	82`38'05"	Louisa, KY	128	42	225
Scioto River (OH)	570.4	Meldahl	39`12'44"	82`51'50"	Higby, OH	134	38	249
Licking River (KY)	752.3	Markland	38`42'31"	84`18'38"	Catawba, KY	116	36	224
Great Miami River (OH)	785.8	Markland	39`23'28"	84`34'20"	Hamilton, OH	94	27	178
Kentucky River (KY)	873.3	McAlpine	38`26'20"	84`57'48"	Lockport, KY	238	81	394
Salt River (KY)	1007.8	Cannelton	37`59'06"	85`43'03"	Shepherdsville, KY	45	13	96
Green River (KY)	1254.7	Myers	37`32'02"	87`15'50"	Calhoun, KY	316	97	660
Wabash River (IN-IL)	1356.8	Smithland	38`24'07"	87`45'10"	Mt. Carmel, IL	797	205	1,705
Cumberland River (KY-TN)	1472.6	Pool 52	36`29'26"	87`50'20"	Dover, TN	693	309	1,123
Tennessee River (KY-TN)	1495.2	Pool 52	35`13'29"	88`15'26"	Savannah, TN	1,559	716	2,259

Table 5. Information pertaining to the raw temperature data extrapolated to estimate average weekly water temperature in each navigation pool (Table 11). Raw data obtained from Environmental Protection Agency's Storet Database at http://www.epa.gov/storet/. ORKm is Ohio River Kilometer measured as distance downstream from Pittsburgh.

Location	First year	Last year	ORKm	Number of observations
South Heights, Pennsylvania	1963	1986	24.5	20,693
Wheeling, West Virginia	1951	1975	139.7	7,920
Evansville, Indiana	1968	1986	1,273.5	14,868
Joppa, Illinois	1975	1986	1,532.3	8,817

Table 6. Kinematic variables used to calculate maximum swimming speeds (U_{max}; Table 8) of target species (after Winter and Van Densen 2001). Median migration temperatures derived from information obtained from proximal sources, for example, Trautman (1981; see Methods); *Rostrum excluded from paddlefish total length.

Species	Base maximum tailbeat frequency - $F_{max\text{-}base}$ (Hz)	Maximum tailbeat frequency at 15°C - $F_{max\text{-}15\,^{\circ}C}$ (Hz)	Maximum tailbeat frequency at median migration temperature - $F_{max\text{-}t}$ (Hz)	Stride length (body lengths)	Median total length of adults (cm)	Median migration temperature °C
Lake sturgeon	15	4.0	3.5	0.7	101	13
Shovelnose sturgeon	15	7.3	7.3	0.7	59	15
Paddlefish	15	5.1	3.9	0.7	84*	11
Longnose gar	20	7.2	9.5	0.4	81.4	19
Shortnose gar	20	9.4	12.4	0.4	62.5	19
Goldeye	25	17.5	11.5	0.7	34	9
Mooneye	25	18.8	12.4	0.7	29.5	9
American eel elver	15	15.0	30.0	0.5	7.5	25
American eel	15	13.2	19.8	0.5	36.8	25
Alabama shad	25	18.0	20.7	0.7	32.5	17
Skipjack herring	25	17.3	15	0.7	35.7	13
Alewife	25	20.3	16.8	0.7	22.6	12
Goldfish	15	13.1	11.4	0.7	17	13
Grass carp	15	4.05	4.3	0.7	100	16
Common Carp	15	6.2	8.1	0.7	72	19
Silver carp	15	5.7	8.5	0.7	77	21
Bighead carp	15	6.3	9.4	0.7	69	21
River carpsucker	15	10.8	16.2	0.7	31	21
Quillback	15	7.9	9.8	0.7	52	18
Highfin carpsucker	15	11.4	13.1	0.7	26.5	17
White sucker	25	18.0	16.7	0.7	33	14
Blue sucker	25	11.3	11.2	0.7	66.5	15
Smallmouth buffalo	15	7.3	9.0	0.7	58	18
Bigmouth buffalo	15	10.05	9.4	0.7	35.5	14
Black buffalo	15	7.9	9.1	0.7	52	17
Spotted sucker	25	17.7	16.5	0.7	32	14
Silver redhorse	25	18.0	13.7	0.7	32.5	11
River redhorse	25	14.5	22.0	0.7	48	21
Black redhorse	25	19.3	19.2	0.7	27.5	15
Golden redhorse	25	19.0	17.7	0.7	28.8	14
Shorthead redhorse	25	16.0	16.0	0.7	40.8	15
White catfish	20	16.6	20.4	0.7	21	18
Blue catfish	20	7.2	10.1	0.7	81	20
Channel catfish	20	14.0	22.7	0.7	33	22
Northern pike	25	13.3	7.6	0.4	57	7
Muskellunge	25	7.5	4.9	0.4	95	9
White perch	25	23.5	17.9	0.7	13.5	11
White bass	25	18.2	21.0	0.7	31.8	17
Yellow bass	25	19.7	21.1	0.7	25.7	16
Striped bass	25	15.5	11.6	0.7	43.1	11
Smallmouth bass	20	13.2	9.37	0.7	38	10
Largemouth bass	20	12.6	12.6	0.7	41	15
Sauger	25	18.0	10.3	0.7	33	7
Walleye	25	17.2	10.7	0.7	35.6	8
Freshwater drum	15	9.4	11.6	0.7	40.6	18

Table 7. Information pertaining to the water surface elevation data used to assess fish passage opportunities at the 20 mainstem dams on the Ohio River. Swellhead is the difference between headwater surface elevation and tailwater surface elevation at the time when gates are first lifted clear of the water.

Dam	Normal pool elevation (m)	Swellhead estimate used to determine open river (m)	Data years	Number of observations	
				Headwater gage	Tailwater gage
Emsworth	216.6	0.153	1995-2000	2,327	2,327
Dashields	211.1	0.153	1980-2000	7,800	7,800
Montgomery	208.0	0.153	1980-2000	7,795	7,795
New Cumberland	202.7	0.153	1980-2000	7,802	7,802
Pike Island	196.4	0.153	1980-2000	7,741	7,740
Hannibal	190.0	0.153	1980-2000	7,740	6,934
Willow Island	184.6	0.153	1975-2000	9,336	9,336
Belleville	177.5	0.153	1975-2000	9,562	9,562
Racine	170.8	0.305	1975-2000	8,468	9,259
R. C. Byrd	164.1	0.153	1975-2000	9,492	9,532
Greenup	157.1	0.305	1975-2000	9,475	9,475
Meldahl	147.9	0.153	1975-2000	9,329	9,557
Markland	138.8	0.153	1975-2000	9,497	9,497
McAlpine	128.1	0.915	1975-2000	9,497	9,497
Cannelton	116.8	0.153	1975-2000	9,418	9,418
Newburgh	109.2	0.153	1975-2000	9,418	9,418
J. T. Myers	104.3	0.153	1975-2000	9,497	9,497
Smithland	98.8	0.153	1981-2000	7,305	7,305
Dam 52	92.1	0.153	1975-2000	9,497	3,624
Dam 53	88.5	0.153	1981-2000	7,309	770

Table 8. Estimated swimming speeds for target fishes of the Ohio River. Prolonged speed (U_{crit10}) is the speed a fish can maintain for 10 min. Burst speed is the speed a fish can maintain for 30 s or less. Maximum swimming speeds ($U_{max\text{-}t}$ and U_{max15}) are kinematically determined speeds for adult-sized fish (TL = total length) at a median spawning migration temperature (Table 6) and at 15°C, respectively (Winter and Van Densen 2001; Equation 1). Shaded areas represent estimates derived from species-specific swimming speeds. Numbers in parenthesis are references cited. Subscripts (o) and (m) indicate method of deriving swimming speeds either directly observed or based on empirical models, respectively. See Table 1 and Appendix A for scientific names.

Species	Median adult TL (cm)	Prolonged speed U_{crit10} ($m\ s^{-1}$)	Burst speed ($m\ s^{-1}$)	Maximum speed $U_{max\text{-}t}$ ($m\ s^{-1}$)	Maximum speed $U_{max\text{-}15}$ ($m\ s^{-1}$)	Surrogate species[a]
Lake sturgeon	101	$0.83_{(m)}$ (12)	$1.55_{(m)}$ (11)	2.49	2.86	---
Shovelnose sturgeon	59	$0.65_{(o)}$ (1), $0.77_{(o)}$ (13)	1.00	3.00	3.00	B-lake sturgeon
Paddlefish	84[b]	$0.65_{(o)}$ (13)	1.40	2.29	3.00	B-lake sturgeon
Longnose gar	81.4	0.45	4.68, 2.50	3.09	2.34	P,B-northern pike
Shortnose gar	62.5	0.45	4.68, 2.50	3.10	2.35	P,B-northern pike
Goldeye	34	$0.8_{(o)}$ (13), $0.6_{(o)}$ (8)	3.47-4.15$_{(o)}$ (15)	2.77	4.20	B-American shad
Mooneye	29.5	0.8, 0.6	3.47-4.15$_{(o)}$ (15)	2.56	3.87	P-goldeye, B-American shad
American eel (elvers)	7.5		<0.50$_{(o)}$ (9)	1.12	0.56	B-European eel elvers
American eel	36.8		$1.14_{(o)}$ (5)	3.63	1.81	B-European eel
Alabama shad	32.5	0.8 (13)	3.47-4.15$_{(o)}$ (15)	4.74	4.12	P-goldeye, B-American shad
Skipjack herring	35.7	0.8 (13)	3.47-4.15$_{(o)}$ (15)	3.75	4.31	P-goldeye, B-American shad
Alewife	22.6	0.6 (8)	4.73 (16)	3.12	4.10	P-goldeye
Goldfish	17	0.83	$1.00_{(o)}$ (2)	1.35	1.55	P-common carp
Grass carp	100	0.83	1.75	3.08	2.88	P,B-common carp
Common carp	72	$0.83_{(m)}$ (14)	$1.17_{(m)}$ (14), $1.75_{(o)}$ (4)	4.03	3.05	---
Silver carp	77	0.83	1.75	4.57	3.05	P,B-common carp
Bighead carp	69	0.83	1.75	4.58	3.05	P,B-common carp
River carpsucker	31	0.83	1.75	3.49	2.32	P,B-common carp
Quillback	52	0.83	1.75	3.59	2.92	P,B-common carp
Highfin carpsucker	26.5	0.83	1.75	2.44	2.12	P,B-common carp
White sucker	33	$0.68_{(m)}$ (8)	$3.30_{(o)}$ (4)	3.87	4.16	B-western sucker
Blue sucker	66.5	$1.02_{(m)}$ (8)	$3.30_{(o)}$ (4)	5.22	5.22	P-longnose sucker, B-western sucker

Table 8 (continued).

Species	Median adult TL (cm)	Prolonged speed $Ucrit_{10}$ ($m\ s^{-1}$)	Burst speed ($m\ s^{-1}$)	Maximum Speed U_{max-t} ($m\ s^{-1}$)	Maximum speed U_{max-15} ($m\ s^{-1}$)	Surrogate species[a]
Smallmouth buffalo	58	0.83	1.75	3.69	3.00	P,B-common carp
Bigmouth buffalo	35.5	0.83	1.75	2.34	2.51	P,B-common carp
Black buffalo	52	0.83	1.75	3.36	2.92	P,B-common carp
Spotted sucker	32	0.66	$3.30_{(o)}$ (4)	3.68	3.96	P-white sucker, B-western sucker
Silver redhorse	32.5	0.54	$3.30_{(o)}$ (4)	3.12	4.10	P-white sucker, B-western sucker
River redhorse	48	$0.85_{(m)}$	$3.30_{(o)}$ (4)	7.38	4.86	P-longnose sucker, B-western sucker
Black redhorse	27.5	0.61	$3.30_{(o)}$ (4)	3.72	3.72	P-white sucker, B-western sucker
Golden redhorse	28.8	0.62	$3.30_{(o)}$ (4)	3.57	3.83	P-white sucker, B-western sucker
Shorthead redhorse	40.8	$0.78_{(m)}$ (8)	$3.30_{(o)}$ (4)	4.59	4.59	P-longnose sucker, B-western sucker
White catfish	21	0.62		3.15	2.09	P-channel catfish
Blue catfish	81	0.71		5.74	4.10	P-channel catfish
Channel catfish	33	$0.71_{(o)}$ (13)		5.28	3.26	---
Northern pike	57	$0.45_{(m)}$ (8)	$4.68_{(o)}$ (14), $2.50_{(o)}$ (4)	1.23	2.83	---
Muskellunge	95	0.6	4.68	1.88	2.85	P,B-northern pike
White perch	13.5	0.78		1.69	2.22	P-white bass
White bass	31.8	$0.78_{(o)}$ (13)	$3.47\text{-}4.15_{(o)}$ (15)	4.66	4.05	B-American shad
Yellow bass	25.7	0.78		3.81	3.56	P-white bass
Striped bass	43.1	$0.86_{(o)}$[c] (7)	$3.47\text{-}4.15_{(o)}$ (15)	3.52	4.69	B-American shad
Smallmouth bass	38	$0.88_{(m)}$ (6)	2.23	2.49	3.50	B-walleye
Largemouth bass	41	$0.60_{(m)}$[c] (3)	2.29	3.61	3.61	B-walleye
Sauger	33	$0.60_{(o)}$ (13)	2.14	2.36	4.14	B-walleye
Walleye	35.6	$0.80_{(m,o)}$ (8,13)	$2.20_{(m)}$ (10)	2.67	4.30	---
Freshwater drum	40.6	$0.75_{(o)}$ (13)		3.28	2.67	---

[a]P = prolonged, B = burst. [b]Rostrum excluded. [c]U_{crit30}.

References: (1) Adams et al. 1997; (2) Bainbridge 1960; (3) Beamish 1970; (4) Blaxter 1969; (5) Blaxter and Dicksen 1958; (6) Bunt et al. 1999; (7) Freadman 1979; (8) Jones et al. 1974; (9) McCleave 1980; (10) Peake et al. 2000; (11) Peake et al. 1997; (12) Peake et al. 1995; (13) Tunink 1975; (14) Videler 1993; (15) Weaver 1965; (16) Wardle and He 1988.

Table 9. Percent of years that Ohio River mainstem dams were at open river (i.e., tailwater elevation greater than normal pool elevation minus swellhead) for at least one day during a particular calendar week in 20 to 26 years. Data years are consecutive, with the last year of data being 2000. Frequency of open river at Emsworth Dam is based on 6 years of actual data and 16 years of estimated data (see Methods). Dark shading ≥50% of years; medium shading <50% and ≥30%; light shading <30% and ≥10%; no shading <10%. Swellhead is the difference between headwater surface elevation and tailwater surface elevation at the time when gates are first lifted clear of the water. D53 is Dam 53, D52 is Dam 52, Smi is Smithland Dam, Mye is J. T. Myers Dam, Neb is Newburgh Dam, Can is Cannelton Dam, Mca is McAlpine Dam, Mar is Markland Dam, Mel is Meldahl Dam, Gre is Greenup Dam, Byr is R. C. Byrd Dam, Rac is Racine Dam, Bel is Belleville Dam, Wil is Willow Island Dam, Han is Hannibal Dam, Pik is Pike Island Dam, Nec is New Cumberland Dam, Mon is Montgomery Dam, Das is Dashields Dam, and Ems is Emsworth Dam. Table on facing page.

Dam →	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Years of data →	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
↓Week of year																				
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 10. Mean, standard deviation (std), and range of the number of days that Ohio River mainstem dams were at open river (i.e., tailwater elevation greater than normal pool elevation minus swellhead) during weeks in which that dam reached open river for at least one day. Swellhead is the difference between headwater surface elevation and tailwater surface elevation at the time when gates are first lifted clear of the water.

Dam	Mean (days)	Std (days)	Range (days)	Number of open-river weeks	Years of data
Dam 53	6.8	0.9	1-7	964	20
Dam 52	6.2	1.6	1-7	743	26
Smithland	5.0	2.1	1-7	162	20
J. T. Myers	5.2	2.1	1-7	357	26
Newburgh	4.9	2.2	1-7	453	26
Cannelton	3.8	2.2	1-7	158	26
McAlpine	3.5	2.1	1-7	131	26
Markland	2.8	1.9	1-7	34	26
Meldahl	3.0	1.9	1-7	100	26
Greeenup	3.0	1.6	1-7	124	26
R. C. Byrd	2.8	1.6	1-7	143	26
Racine	2.3	1.3	1-6	71	26
Belleville	1.8	0.8	1-3	28	26
Willow Island	1.8	0.8	1-3	29	26
Hannibal	1.3	0.6	1-2	3	21
Pike Island	1.8	0.7	1-3	12	21
New Cumberland	1.4	0.5	1-2	9	21
Montgomery	1.1	0.3	1-2	9	21
Dashields	1.8	1.3	1-6	43	21
Emsworth	1.0	0	1	4	21

Table 11. Estimated water temperatures at Ohio River mainstem dam by calendar week. Shading darkens with increasing temperature. Data from four stations along the Ohio River (Environmental Protection Agency's Storet Database at http://www.epa.gov/storet/; Table 5) were used to derive these values. D53 is Dam 53, D52 is Dam 52, Smi is Smithland Dam, Mye is J. T. Myers Dam, Neb is Newburgh Dam, Can is Cannelton Dam, Mca is McAlpine Dam, Mar is Markland Dam, Mel is Meldahl Dam, Gre is Greenup Dam, Byr is R. C. Byrd Dam, Rac is Racine Dam, Bel is Belleville Dam, Wil is Willow Island Dam, Han is Hannibal Dam, Pik is Pike Island Dam, Nec is New Cumberland Dam, Mon is Montgomery Dam, Das is Dashields Dam, and Ems is Emsworth Dam.

Dam→ ↓Week of year	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
39 – Sep	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	22	22	21	21
40 – Oct	21	21	21	22	22	22	22	22	22	22	22	22	22	21	21	21	21	20	19	19
41 – Oct	19	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	19	18	18	18
42 – Oct	18	18	18	19	19	19	19	19	19	19	19	19	19	19	19	19	18	17	16	16
43 – Oct	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	16	16	15	15
44 – Oct/Nov	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	15	14	14	14
45 – Nov	15	15	15	15	14	14	14	14	14	14	14	14	14	14	14	14	13	13	12	12
46 – Nov	13	12	12	12	12	13	13	13	13	13	13	13	13	13	13	13	12	11	10	10
47 – Nov	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	10	9	9	9
48 – Nov/ Dec	9	9	9	10	10	10	9	9	9	9	9	9	9	9	9	9	8	8	7	7
49 – Dec	7	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	7	6	6	6
50 – Dec	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6	6	5	5
51 – Dec	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	4	4
52 – Dec	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	4	3	3	3
1 – Jan	5	5	5	4	4	4	4	4	4	4	4	5	5	5	5	5	4	3	3	3
2 – Jan	4	4	4	4	3	3	3	4	4	4	4	4	4	4	4	4	3	3	2	2
3 – Jan	4	4	4	4	3	3	3	4	4	4	4	4	4	4	4	4	3	2	2	2
4 – Jan	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3
5 – Jan/Feb	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	2	2
6 – Feb	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	2	2
7 – Feb	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3
8 – Feb	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	4	4	4	4
9 – Feb/Mar	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	4	4
10 – Mar	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5	5
11 – Mar	8	8	8	7	7	7	7	7	7	7	7	7	7	7	7	7	6	6	6	6
12 – Mar	9	9	9	9	8	8	8	8	8	8	8	7	7	7	7	7	7	7	7	7
13 – Mar/Apr	10	10	9	9	9	9	9	8	8	8	8	8	8	8	8	8	8	8	8	8
14 – Apr	12	12	12	11	10	10	10	10	10	10	9	9	9	9	9	9	9	9	9	9
15 – Apr	13	13	13	12	12	12	11	11	11	11	11	11	10	10	10	10	10	10	10	10
16 – Apr	15	14	14	14	14	14	13	13	13	12	12	12	12	12	12	12	12	12	12	12
17 – Apr	16	16	16	15	15	15	15	15	14	14	14	14	14	14	14	14	14	14	14	14
18 – Apr/May	17	17	17	17	16	16	16	16	16	16	15	15	15	15	15	15	15	15	15	15
19 – May	18	18	18	18	18	18	17	17	17	17	17	17	17	17	17	17	17	16	16	16
20 – May	20	20	19	19	19	19	18	18	18	18	18	18	17	17	17	17	17	17	18	18
21 – May	21	21	21	20	20	20	20	20	20	19	19	19	19	19	19	19	19	19	19	19
22 – May/Jun	22	22	22	22	22	21	21	21	21	21	21	21	20	20	20	20	20	20	20	20
23 – Jun	23	23	23	23	23	23	22	22	22	22	22	22	22	22	22	22	22	22	22	22
24 – Jun	25	25	25	24	24	24	24	24	24	24	24	24	24	24	24	24	23	23	23	23
25 – Jun	26	26	26	25	25	25	25	25	25	25	25	25	25	25	25	24	24	24	24	24
26 – Jun/Jul	27	27	27	26	26	26	26	26	26	25	25	25	25	25	25	25	25	24	24	24
27 – Jul	27	27	27	27	27	27	27	26	26	26	26	26	26	26	26	26	26	25	25	25
28 – Jul	28	28	28	28	28	27	27	27	27	27	27	26	26	26	26	26	26	26	26	26
29 – Jul	29	29	29	28	28	28	28	28	27	27	27	27	27	27	27	27	27	27	26	26
30 – Jul	29	29	29	29	28	28	28	28	28	28	28	27	27	27	27	27	27	27	27	27
31 – Jul/Aug	29	29	29	28	28	28	28	28	28	28	28	28	28	28	28	27	27	27	27	27
32 – Aug	29	29	29	28	28	28	28	28	28	27	27	27	27	27	27	27	27	27	27	27
33 – Aug	29	28	28	28	28	28	28	28	27	27	27	27	27	27	27	27	26	26	26	26
34 – Aug	28	28	28	28	28	28	28	27	27	27	27	27	27	27	27	27	26	26	26	26
35 – Aug/Sep	28	28	28	28	28	28	27	27	27	27	27	27	27	27	27	27	26	26	26	26
36 – Sep	27	27	27	27	27	27	27	27	27	26	26	26	26	26	26	26	26	25	25	25
37 – Sep	26	26	26	26	26	26	26	26	26	25	25	25	25	25	25	25	25	24	24	24
38 – Sep	25	25	25	25	25	25	24	24	24	24	24	24	24	24	24	24	23	23	23	23

Table 12. General life history characteristics, occurrence by reach, and distribution of the 44 target species in the Ohio River. Occurrence– A is absent and P is present based on Pearson and Pearson (1989) for the lower (Ohio River Kilometer [ORKm] 1,053 to 1,578), middle (ORKm 527 to 1,052), and upper (ORKm 0 to 526) reaches of the Ohio River between 1970 and 1988; in parentheses, A is absent, U is uncommon, O is occasional, and C is common in standardized lock rotenone samples (ORSANCO 2001) and night electrofishing samples (OEPA 2002) collected between 1989 and 2001. General distribution group– E is extirpated, L is more common in lower reach than middle and upper reaches, LM is more common in lower and middle reaches than the upper reach, LMU common in all three reaches, MU more common in the middle and upper reaches than the lower reach, and U more common in the upper reach than in middle and lower reaches based on occurrence columns. General habitat after Koel (unpublished data); pelagic/benthic after Winemiller and Rose (1992); reproductive strategy after Simon (1999), Balon (1975), or Pearson and Krumholz (1984); pollution tolerance after Lyons et al. (2001), Simon and Emery (1995), or Pearson and Krumholz (1984); spawning temperature and migratory status generally based on proximal sources, for example, Trautman (1981; see Methods).

Common name	General habitat	Pelagic or benthic	Migatory	Spawning temperature °C	Reproductive strategy	Pollution tolerant or sensitive	Occurrence			General distribu-tion group
							Lower reach	Middle reach	Upper reach	
Lake sturgeon	Fluvial dependent	Benthic	Yes*	8.5-21	Nonguarder litho-pelagophil	Sensitive	A (A)	A (A)	A (A)	E
Shovelnose sturgeon	Fluvial specialist	Benthic	Yes	15.5-21.5	Nonguarder litho-pelagophil	Sensitive	P (A)	P (A)	A (A)	L
Paddlefish	Fluvial dependent	Pelagic	Yes *	10-16	Nonguarder litho-pelagophil	Sensitive	P (O)	P (O)	P (A-O)	LM
Longnose gar	Fluvial dependent	Pelagic	Yes	21	Nonguarder phyto-lithophil	Tolerant	P (A-C)	P (O-C)	P (A-C)	LMU
Shortnose gar	Macrohabitat generalist	Pelagic	--	19-24	Nonguarder phytophil	Tolerant	P (A-O)	P (A-O)	P (A)	L
Goldeye	Fluvial dependent	Pelagic	Yes	10-22	Nonguarder litho-pelagophil	Sensitive	P (O-C)	P (U-C)	P (A-U)	LM
Mooneye	Fluvial dependent	Pelagic	Yes	10-13	Nonguarder litho-pelagophil	Sensitive	P (A-C)	P (O-C)	P (A-C)	LMU
American eel	Macrohabitat generalist	Benthic	Yes *	---	Nonguarder pelagophil	--	P (A-C)	P (A-O)	P (A-U)	LM
Alabama shad	Fluvial dependent	Pelagic	Yes *	19-22	Nonguarder lithophil	--	A (A)	A (A)	A (A)	E
Skipjack herring	Fluvial dependent	Pelagic	Yes	Unknown	Nonguarder phyto-lithophil	Tolerant	P (C)	P (C)	P (O-C)	LMU
Alewife	Fluvial dependent	Pelagic	Yes *	13-16	Nonguarder phyto-lithophil	--	A (A)	P (A)	P (A-O)	U
Goldfish	Macrohabitat generalist	Benthopelagic	--	>15	Nonguarder phytophil	Tolerant	P (A)	P (A-U)	P (A-O)	MU
Grass carp	Fluvial dependent	Benthopelagic	--	18-19	Nonguarder pelagophil	--	P (A)	P (A)	A (A)	LM
Common carp	Macrohabitat generalist	Benthopelagic	Yes	17-27	Nonguarder phyto-lithophil	Tolerant	P (C)	P (O-C)	P (C)	LMU
Silver carp	Fluvial dependent	Pelagic	Yes	18-30	Nonguarder pelagophil	--	P (A)	P (A)	A (A)	LM
Bighead carp	Fluvial dependent	Benthopelagic	Yes	18-30	Nonguarder pelagophil	--	A (A-O)	A (A)	A (A)	L
River carpsucker	Macrohabitat generalist	Benthopelagic	Yes	23.9	Nonguarder litho-pelagophil	Tolerant	P (O-C)	P (C)	P (A-C)	LMU
Quillback	Macrohabitat generalist	Benthopelagic	Yes	13-28	Nonguarder litho-pelagophil	Tolerant	P (O-C)	P (O-C)	P (O-C)	LMU
Highfin carpsucker	Fluvial dependent	Benthopelagic	Yes	13-25	Nonguarder litho-pelagophil	Sensitive	P (A-O)	P (O-C)	P (A-O)	LM
White sucker	Macrohabitat generalist	Benthopelagic	Yes	4-20	Nonguarder litho-pelagophil	Tolerant	P (A)	P (A)	P (A-U)	U
Blue sucker	Fluvial specialist	Benthic	Yes	10-23	Nonguarder litho-pelagophil	Sensitive	P (A-O)	P (A-O)	P (A)	L

Table 12 (continued).

Common name	General habitat	Pelagic or benthic	Migatory	Spawning temperature °C	Reproductive strategy	Pollution tolerant or sensitive	Occurrence			General distribu-tion group
							Lower reach	Middle reach	Upper reach	
Smallmouth buffalo	Macrohabitat generalist	Benthopelagic	Yes	15.5-27	Nonguarder phyto-lithophil	Tolerant	P (C)	P (C)	P (A-C)	LMU
Bigmouth buffalo	Macrohabitat generalist	Benthopelagic	Yes	15.5-18.3	Nonguarder phytophil	Tolerant	P (O-C)	P (A-O)	P (A-U)	L
Black buffalo	Macrohabitat generalist	Benthopelagic	--	18-21	Nonguarder phytophil	Sensitive	P (A-C)	P (A-O)	P (A-C)	LMU
Spotted sucker	Macrohabitat generalist	Benthic	Yes	12.2-19.4	Nonguarder lithophil	Sensitive	P (A)	P (A-C)	P (A-C)	U
Silver redhorse	Macrohabitat generalist	Benthopelagic	Yes	13-13.3	Nonguarder lithophil	Sensitive	P (A)	P (A-C)	P (A-C)	MU
River redhorse	Fluvial specialist	Benthopelagic	Yes	22-25	Nonguarder lithophil	Sensitive	P (A)	P (A-O)	P (A-C)	MU
Black redhorse	Fluvial dependent	Benthopelagic	Yes	13-23	Nonguarder lithophil	Sensitive	A (A)	P (A-U)	P (A-C)	U
Golden redhorse	Fluvial dependent	Benthopelagic	Yes	10-15.5	Nonguarder lithophil	Sensitive	P (A)	P (A-C)	P (A-C)	MU
Shorthead redhorse	Fluvial dependent	Benthopelagic	Yes	11-22	Nonguarder lithophil	Sensitive	P (A-O)	P (A-C)	P (A-C)	MU
White catfish	Macrohabitat generalist	Benthic	--	20-22.2	Guarder spelophil	--	P (A-O)*	P (A-O)*	P (A)	LM
Blue catfish	Fluvial specialist	Benthic	Yes	21-24	Guarder spelophil	--	P (O-C)	P (A-C)	P (A)	L
Channel catfish	Macrohabitat generalist	Benthic	Yes	23.9-26.7	Guarder spelophil	Tolerant	P (C)	P (C)	P (C)	LMU
Northern pike	Macrohabitat generalist	Pelagic	Yes	4-11	Nonguarder phytophil	--	A (A)	P (A)	P (A)	MU
Muskellunge	Macrohabitat generalist	Pelagic	Yes	8.9-13.3	Nonguarder phytophil	Sensitive	A (A)	P (A)	P (A)	MU
White perch	Fluvial dependent	Pelagic	Yes *	11-16	Nonguarder phyto-lithophil	--	A (A)	A (A)	A (A-O)	U
White bass	Fluvial dependent	Pelagic	Yes	12.5-26.1	Nonguarder phyto-lithophil	Tolerant	P (C)	P (C)	P (O-C)	LMU
Yellow bass	Fluvial dependent	Benthopelagic	Yes	>15	Nonguarder phyto-lithophil	--	P (A-C)	P (A-U)	P (A)	L
Striped bass	Fluvial dependent	Benthopelagic	Yes *	>14.4	Nonguarder phyto-lithophil	--	P (O-C)	P (O-C)	P (A-O)	LM
Smallmouth bass	Macrohabitat generalist	Benthopelagic	Yes	>4-16.6	Guarder polyphil	Sensitive	P (A-O)	P (A-C)	P (O-C)	MU
Largemouth bass	Macrohabitat generalist	Benthopelagic	--	15.5-21.1	Guarder polyphil	--	P (O-C)	P (C)	P (A-C)	LMU
Sauger	Macrohabitat generalist	Benthopelagic	Yes	3.9-11	Nonguarder litho-pelagophil	--	P (C)	P (C)	P (C)	LMU
Walleye	Macrohabitat generalist	Benthopelagic	Yes	5.6-11.1	Nonguarder litho-pelagophil	Sensitive	P (O-C)	P (A-C)	P (O-C)	LMU
Freshwater drum	Macrohabitat generalist	Benthopelagic	Yes	19-22	Nonguarder pelagophil	Tolerant	P (C)	P (C)	P (C)	LMU

* Indicates highly migratory

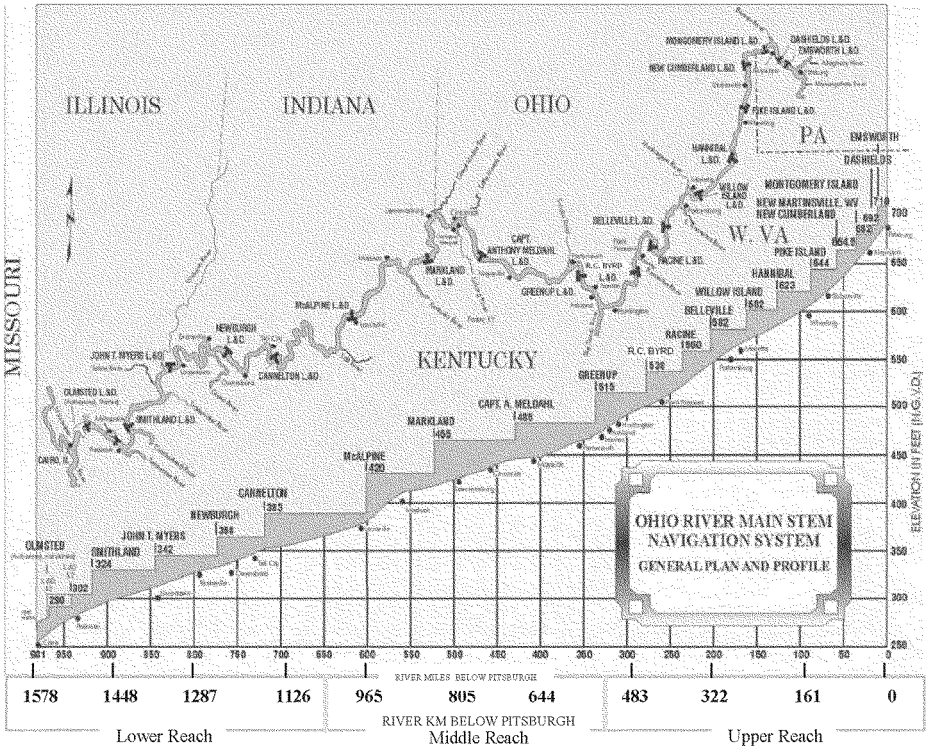

Figure 1. Map showing the locations of the 20 mainstem dams on the Ohio River between its source at the confluence of the Allegheny and Monongahela Rivers to its confluence with the Mississippi River near Cairo, Illinois (Figure modified from the U.S. Army Corp of Engineers' Web site at http://www.lrl.usace.army.mil/ormss/). Reaches are equivalent to those defined in Pearson and Pearson (1989).

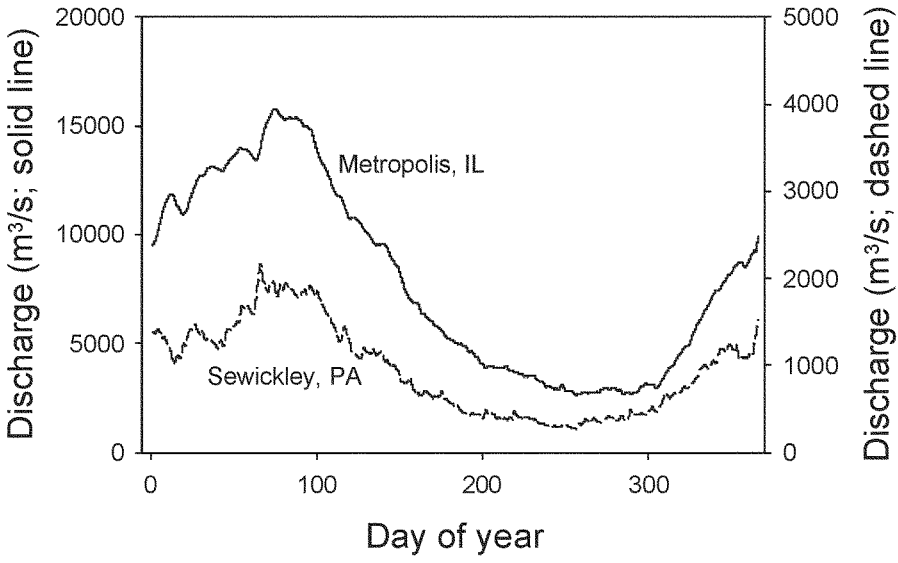

Figure 2. The mean annual discharge at Sewickley, Pennsylvania (*dashed line*; right y-axis), near the source of the Ohio River and at Metropolis, Illinois (*solid line*; left y-axis), near the mouth of the Ohio River. Derived from raw data from the U.S. Geological Survey's Web site http://water.usgs.gov/).

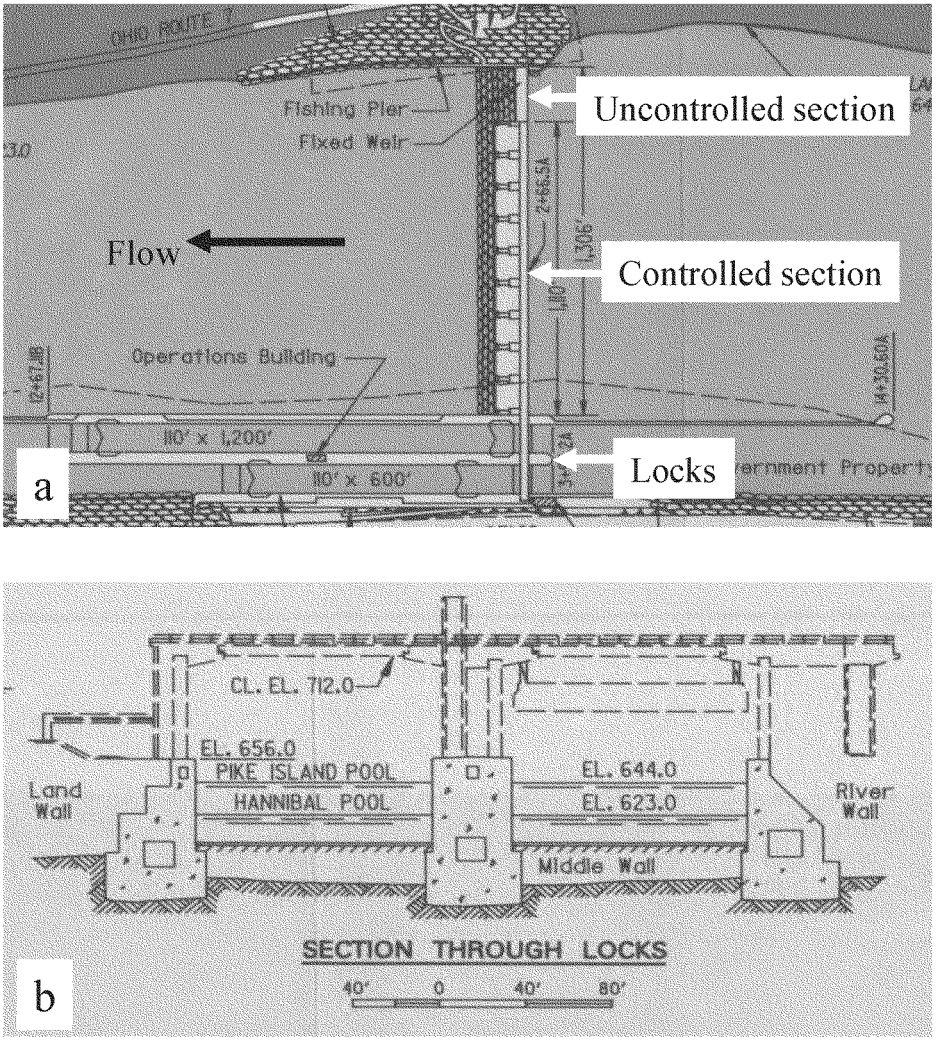

Figure 3. (*a*) Diagram of a typical mainstem dam showing the three primary sections including the uncontrolled section (fixed weir), controlled section (gated portion), and the locks. (*b*) Section view through the locks at Pike Island Dam. Diagrams are from project plans on District Web sites served by the U.S. Army Corps of Engineers.

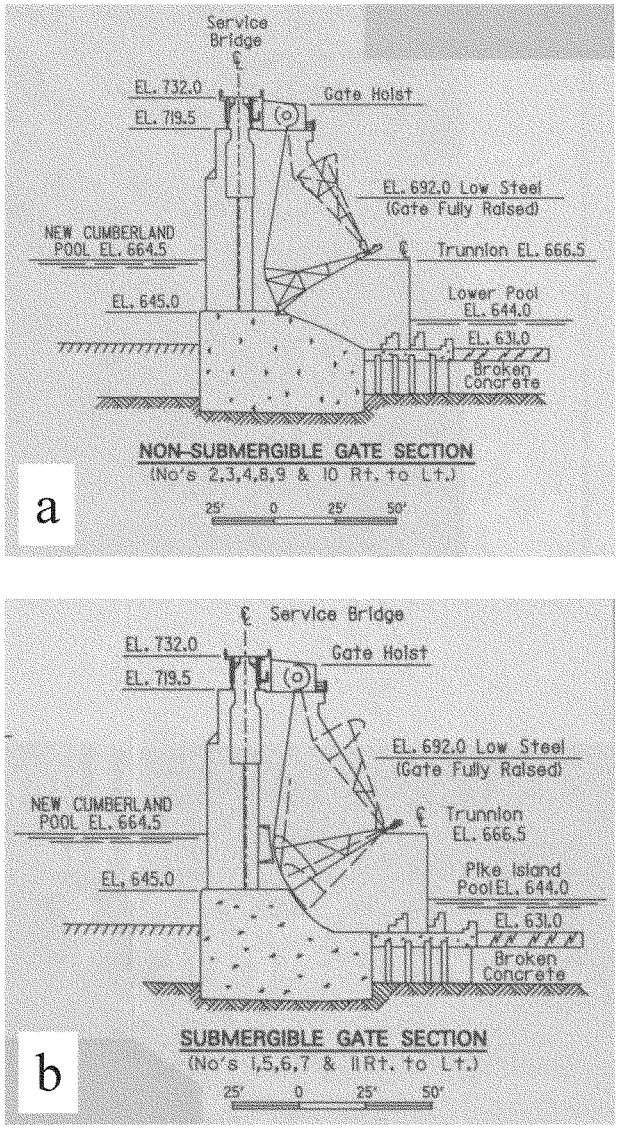

Figure 4. Diagrams of typical (*a*) non-submergible and (*b*) submergible tainter gates found on the controlled sections of mainstem dams on the Ohio River. Diagrams are from project plans on District Web sites served by the U.S. Army Corps of Engineers.

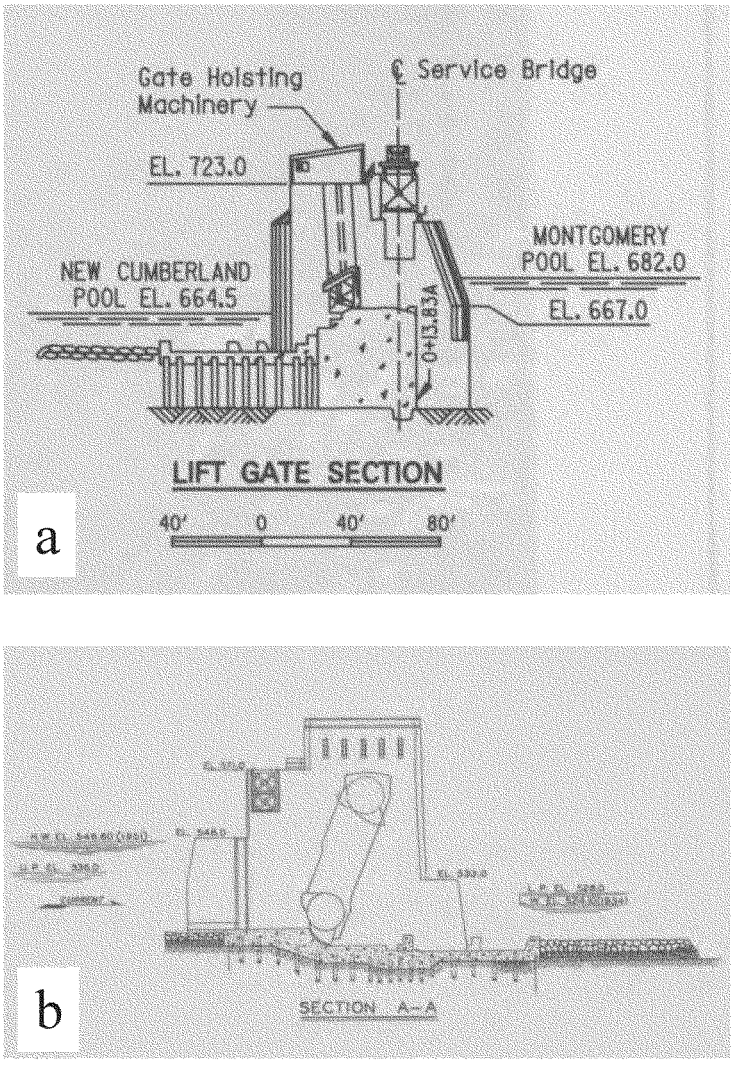

Figure 5. Diagrams of typical (*a*) Sydney-type lift gate and (*b*) roller gate found on the controlled sections of mainstem dams on the Ohio River. Diagrams are from project plans on District Web sites served by the U.S. Army Corps of Engineers.

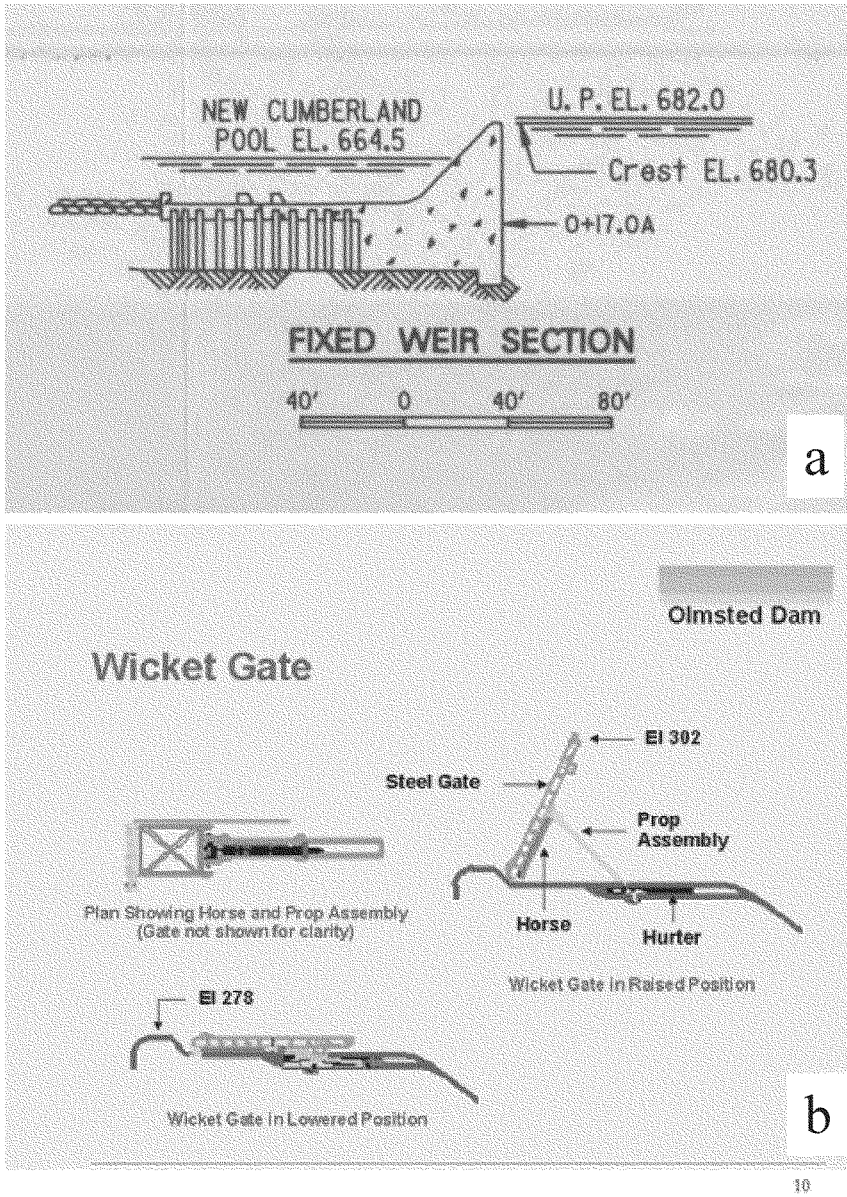

Figure 6. (*a*) Diagram of a typical fixed-weir found on the uncontrolled sections of mainstem dams on the Ohio River. (*b*) Illustration of a movable section of a wicket-type dam similar to those found at Dams 52 and 53 on the Ohio River. Diagrams are from project plans on District Web sites served by the U.S. Army Corps of Engineers.

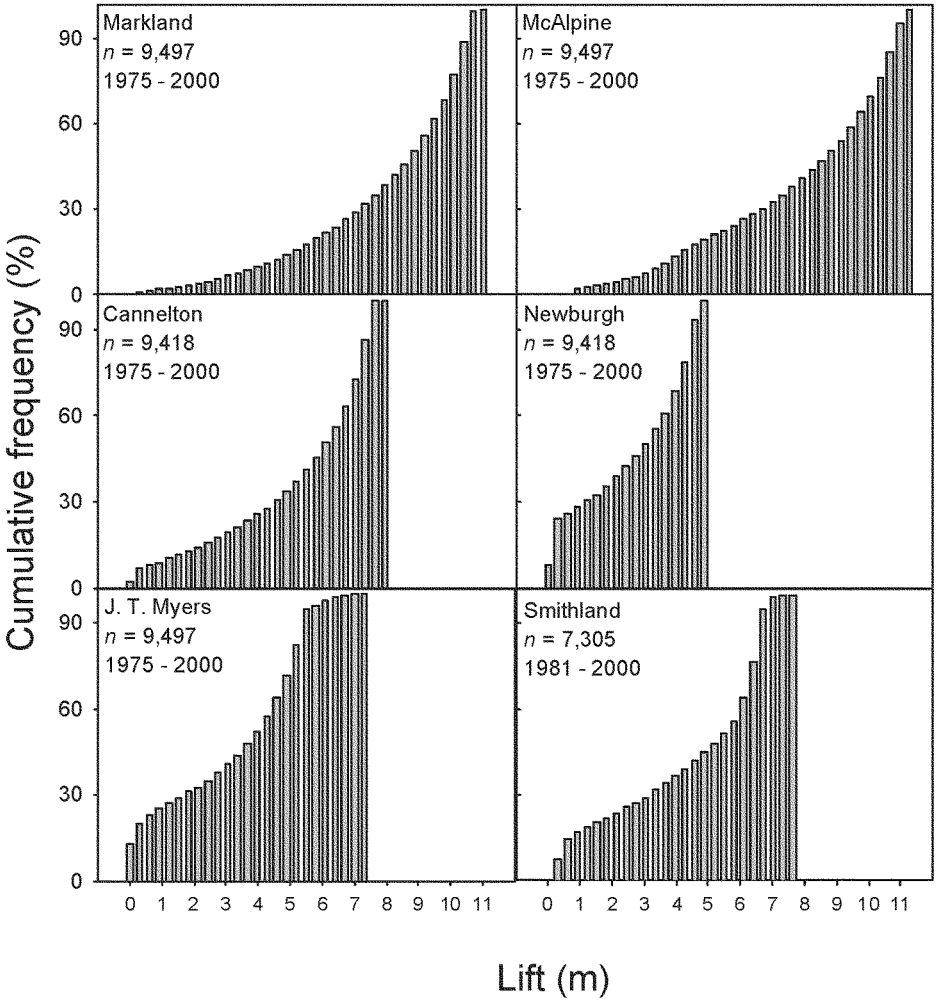

Figure 7a. Cumulative frequency of lift (headwater elevation minus tailwater elevation) at Ohio River mainstem dams in the Louisville District. *n* = number of daily observations.

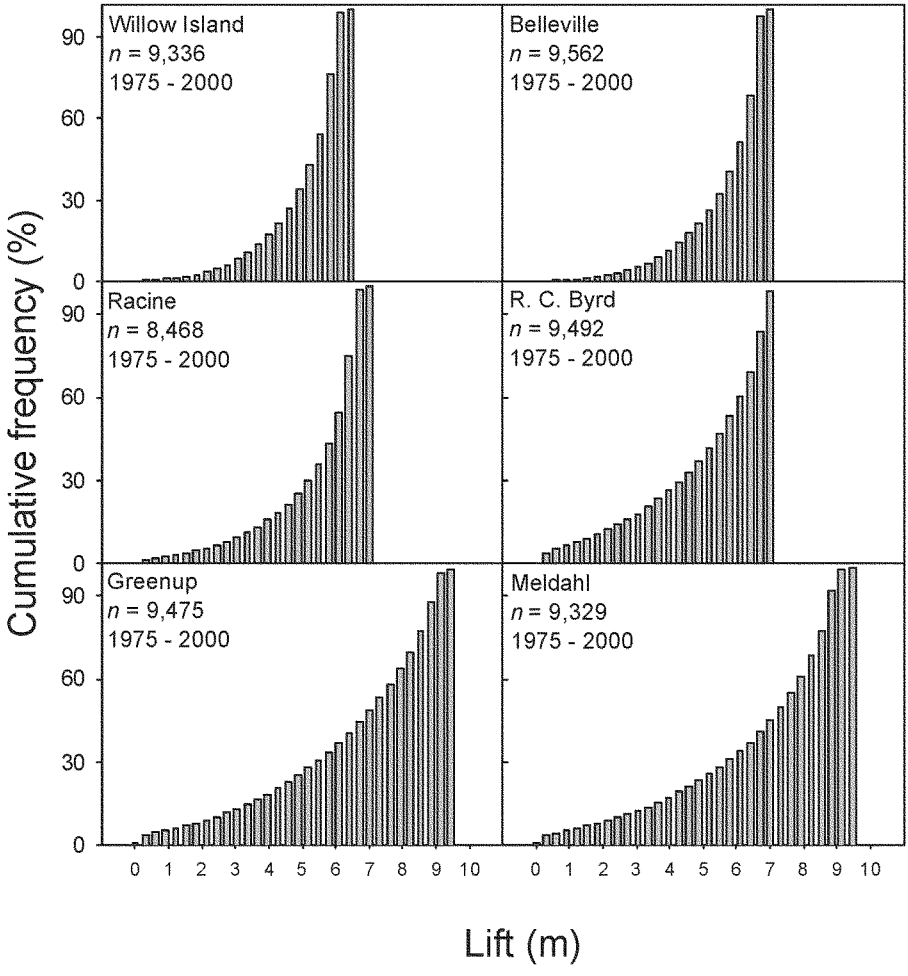

Figure 7b. Cumulative frequency of lift (headwater elevation minus tailwater elevation) at Ohio River mainstem dams in the Huntington District. *n* = number of daily observations.

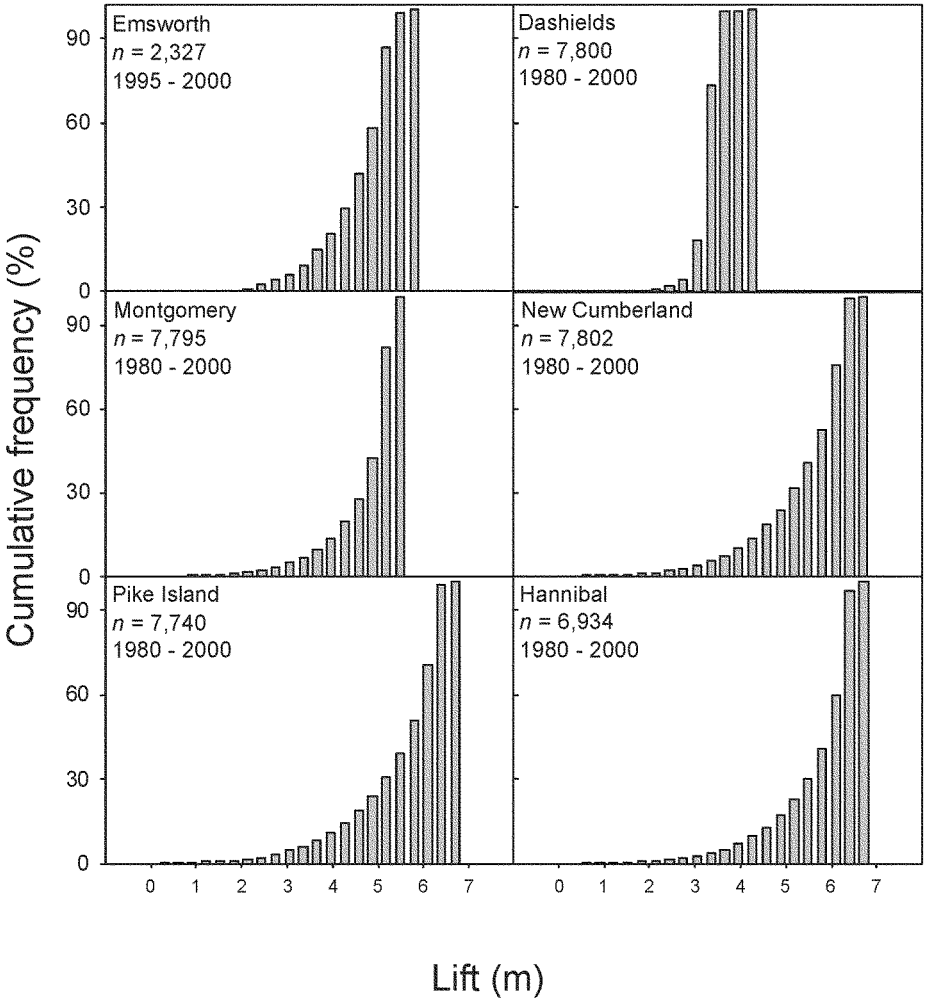

Figure 7c. Cumulative frequency of lift (headwater elevation minus tailwater elevation) at Ohio River mainstem dams in the Pittsburgh District. n = number of daily observations.

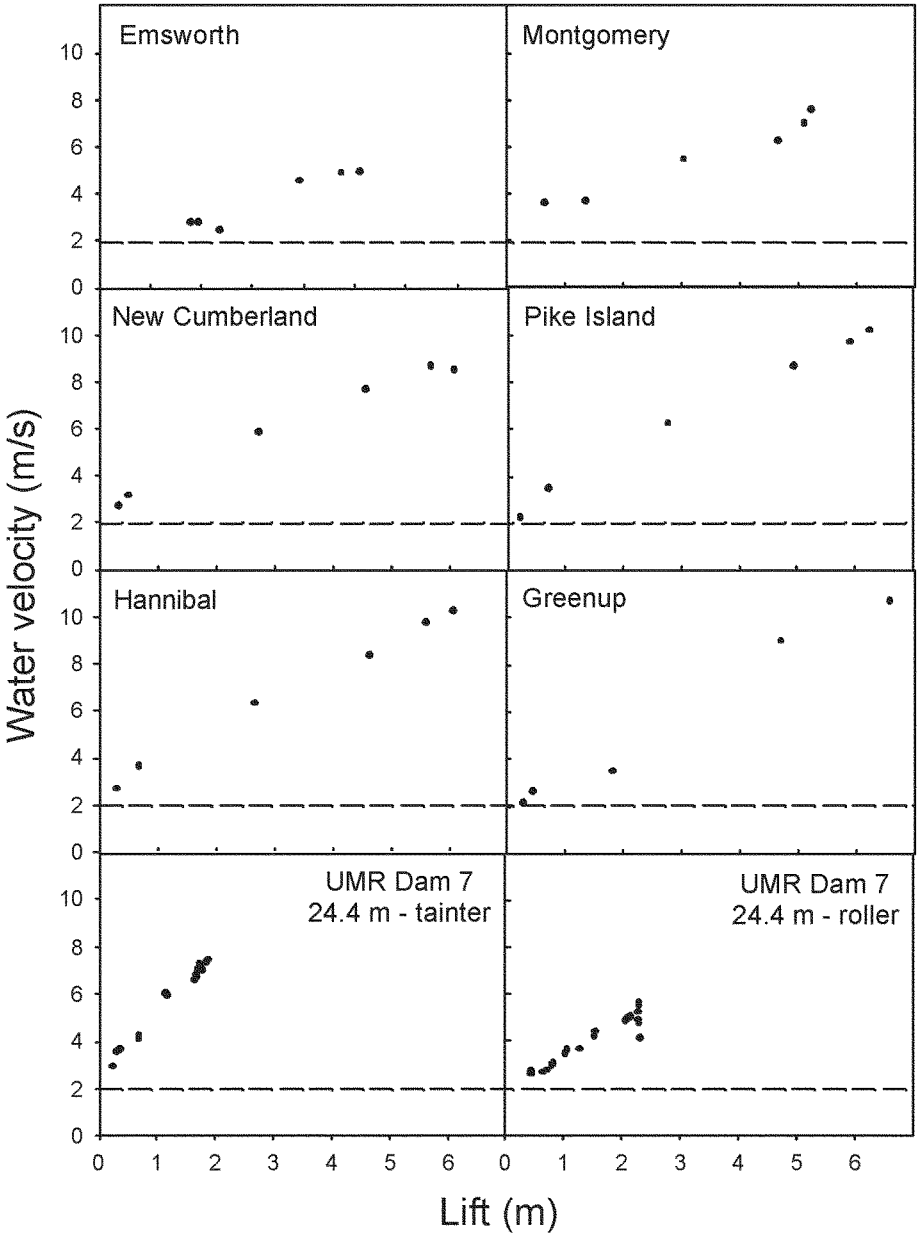

Figure 8. Estimated water velocities through the gate openings of mainstem dams on the Ohio River and at Lock and Dam 7 on the Upper Mississippi River (UMR) at various lifts. Dashed line is 2.0 m/s.

Appendix A: List of the common and scientific names of five surrogate species used to estimate swimming speeds of target species (Table 8).

Common name	Scientific name
European eel	*Anguilla anguilla*
American shad	*Alosa sapidissima*
Longnose sucker	*Catostomus catostomus*
Sacramento sucker	*C. occidentalis*
Rainbow trout	*Oncorhynchus mykiss*

Appendix B: Occurrence and distribution information and estimated spawning migration period *shaded* over the frequency of open river by navigation pool (Table 9) for the 44 target species from the Ohio River. See Table 1 for scientific names. D53 is Dam 53, D52 is Dam 52, Smi is Smithland Dam, Mye is J. T. Myers Dam, Neb is Newburgh Dam, Can is Cannelton Dam, Mca is McAlpine Dam, Mar is Markland Dam, Mel is Meldahl Dam, Gre is Greenup Dam, Byr is R. C. Byrd Dam, Rac is Racine Dam, Bel is Belleville Dam, Wil is Willow Island Dam, Han is Hannibal Dam, Pik is Pike Island Dam, Nec is New Cumberland Dam, Mon is Montgomery Dam, Das is Dashields Dam, and Ems is Emsworth Dam.

Lines 2 and 3 of each table. Distribution information is from Pearson and Pearson (1989). The two periods are original (1800 to 1969; O) and recent (since 1970; R). The three river reaches are upper (ORKm 0 to 526), middle (ORKm 527 to 1,052), and lower (ORKm 1,053 to 1,578). Reaches are separated by a vertical line. Shaded blocks with a "P" indicate that the species was present in that reach during that period. Unshaded blocks with an "A" indicate that the species was absent in that reach during that period.

Line 4 of each table. Recent occurrence information by navigation pool is based on our analysis of lock rotenone (ORSANCO 2001) and night electrofishing samples (OEPA 2002) between 1989 and 2001. "A" (absent) indicates that the species was absent in all samples; "U" (uncommon) indicates that the species occurred in less than 15% of samples; "O" (occasional) indicates that the species occurred in 15 to 50% of samples; "C" (common) indicates that the species occurred in greater than 50% of the samples; and --- indicates no information was available.

Lines 6 to 57 of each table. The percent of past years (i.e., 20 to 26 years) that a particular calendar week was at open river for each mainstem dam (Table 9). For a calendar week to be considered an open-river week in the frequency analysis that dam had to be open at least one day during that week. Migration period (*shaded*) for each species is estimated as the range of spawning temperatures reported in the literature (*dark shading*; Table 12) and 4 weeks before the lowest reported spawning temperature (*light shading*). Estimated water temperature by calendar week and navigation pool is shown in Table 11.

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	A						A			A										
Occurrence (89-01)	---	---	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Lake sturgeon

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P								P					
Distribution (R)	P						P				A									
Occurrence (89-01)	----	----	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	12	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	12	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Shovelnose sturgeon

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	A	O	O	O	O	O	O	O	A	O	A	A	A	U	A	A	A	A
Yrs of data→ ⇓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	16	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Paddlefish

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P					P														
Distribution (R)	P					P														
Occurrence (89-01)	----	----	A	O	C	O	C	C	C	C	O	C	C	C	O	C	O	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	12	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Longnose gar

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P				P									
Distribution (R)	P						P				P									
Occurrence (89-01)	---	---	O	O	A	O	A	A	U	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	0	5	5	5	10	5	
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Shortnose gar

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P				P									
Distribution (R)	P						P				P									
Occurrence (89-01)	----	----	C	O	O	O	C	O	O	U	A	A	A	A	A	U	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	4	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	15	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Goldeye

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	C	C	A	C	O	C	C	C	O	C	O	O	O	O	O	O	C	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Mooneye

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)			P				P					P								
Distribution (R)			P				P					P								
Occurrence (89-01)	----	----	C	A	O	O	A	O	U	U	A	U	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

American eel

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						P			A										
Distribution (R)	A					A				A										
Occurrence (89-01)	----	----	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Alabama shad

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)			P				P			P										
Distribution (R)			P				P			P					P					
Occurrence (89-01)	---	---	C	C	C	C	C	C	C	C	C	C	C	O	O	C	O	C	C	O
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	15	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Skipjack herring

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A							A		A					A					
Distribution (R)	A					P				P										
Occurrence (89-01)	---	---	A	A	A	A	A	A	A	A	U	A	A	U	A	O	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Alewife

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	---	---	A	A	A	A	A	U	A	O	U	O	O	U	A	U	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Goldfish

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A							A			A									
Distribution (R)	P						P				A									
Occurrence (89-01)	---	---	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Grass carp

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)			P				P								P					
Distribution (R)			P				P								P					
Occurrence (89-01)	----	----	C	C	C	C	O	C	C	C	C	C	C	C	C	C	C	C	C	C
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	3	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Common carp

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A							A		A										
Distribution (R)	P						P			A										
Occurrence (89-01)	---	---	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	48	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Silver carp

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A							A		A					A					
Distribution (R)	A							A							A					
Occurrence (89-01)	----	----	A	O	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	95	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Bighead carp

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	O	C	C	C	C	C	C	C	C	C	C	C	O	C	O	O	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

River carpsucker

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)			P				P			P					P					
Distribution (R)			P				P			P					P					
Occurrence (89-01)	----	----	O	C	C	C	O	C	C	C	C	C	C	C	O	C	C	C	C	O
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Quillback

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	A	O	O	O	O	O	C	O	A	U	U	A	A	A	U	O	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	8	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Highfin carpsucker

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A					P				P										
Distribution (R)	P					P				P										
Occurrence (89-01)	----	----	A	A	A	A	A	A	A	A	A	U	A	A	A	U	U	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	58	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

White sucker

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	A	A	O	O	A	U	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Blue sucker

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	A	O
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Smallmouth buffalo

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P					P				P										
Occurrence (89-01)	----	----	C	C	C	O	O	U	O	A	A	U	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Bigmouth buffalo

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	A	C	A	O	A	O	O	O	C	O	O	O	A	O	U	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Black buffalo

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P							P		P										
Distribution (R)	P							P		P										
Occurrence (89-01)	----	----	A	A	A	A	A	O	U	C	U	O	C	C	O	O	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	58	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Spotted sucker

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P													
Distribution (R)	P						P									P				
Occurrence (89-01)	----	----	A	A	A	A	A	C	C	O	O	C	C	O	A	O	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Silver redhorse

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	A	A	A	A	O	O	O	O	O	U	C	A	U	O	O	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	19	23	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

River redhorse

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A					P				P										
Distribution (R)	A					P				P										
Occurrence (89-01)	----	----	A	A	A	A	A	U	A	U	O	A	C	C	C	C	C	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Black redhorse

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Modern	----	----	A	A	A	A	O	C	C	C	C	O	C	C	C	C	C	O	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Golden redhorse

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P					P								
Distribution (R)	P						P					P								
Modern	----	----	A	O	O	O	A	C	C	C	C	C	C	O	O	C	C	C	A	C
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Shorthead redhorse

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A						A			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	A	A	A	O	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

White catfish

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	C	C	O	C	A	U	U	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Blue catfish

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Channel catfish

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A					P				A										
Distribution (R)	A					P				P										
Occurrence (89-01)	----	----	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	30	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Northern pike

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A					P				P										
Distribution (R)	A					P				P										
Occurrence (89-01)	----	----	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Muskellunge

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)			A					A			A				A					
Distribution (R)			A					A			A				A					
Occurrence (89-01)	----	----	A	A	A	A	A	A	A	A	O	O	A	A	A	U	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	35	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	16	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

White perch

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Hart	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P					P								
Distribution (R)	P						P					P								
Occurrence (89-01)	----	----	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	O
Yrs of data→ ⇩Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	60	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

White bass

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)			P					A							A					
Distribution (R)			P					P							P					
Occurrence (89-01)	----	----	C	O	A	A	A	A	U	A	A	A	A	A	A	A	A	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Yellow bass

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	A							A		A					A					
Distribution (R)	P							P		P					P					
Occurrence (89-01)	----	----	O	C	C	C	O	C	C	O	U	O	O	O	U	A	O	A	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Striped bass

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P													
Distribution (R)	P						P													
Occurrence (89-01)	----	----	A	O	A	A	O	C	C	C	C	O	C	C	C	C	C	O	C	O
Yrs of data→ ↓Week of year	20	20	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Smallmouth bass

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P							P		P										
Distribution (R)	P					P				P										
Occurrence (89-01)	----	----	O	O	C	C	C	C	C	C	C	C	C	C	O	C	O	O	A	A
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	40	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Largemouth bass

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)			P				P			P					P					
Distribution (R)			P				P			P					P					
Occurrence (89-01)	----	----	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	4	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Sauger

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P						P			P										
Distribution (R)	P						P			P										
Occurrence (89-01)	----	----	O	O	C	C	A	O	O	C	C	C	O	O	C	C	C	C	C	O
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Walleye

Dam→	D53	D52	Smi	Mye	Neb	Can	Mca	Mar	Mel	Gre	Byr	Rac	Bel	Wil	Han	Pik	Nec	Mon	Das	Ems
Distribution (O)	P							P				P								
Distribution (R)	P							P				P								
Occurrence (89-01)	----	----	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Yrs of data→ ↓Week of year	20	26	20	26	26	26	26	26	26	26	26	26	26	26	21	21	21	21	21	21
39 – Sep	75	30	0	4	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
40 – Oct	60	35	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 – Oct	65	35	0	0	8	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0
42 – Oct	70	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 – Oct	75	45	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 – Oct/Nov	75	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 – Nov	85	45	0	4	8	0	0	0	4	4	4	4	4	4	0	5	5	5	10	5
46 – Nov	95	65	0	8	15	0	0	0	0	4	8	4	4	4	0	5	0	0	5	0
47 – Nov	85	65	0	8	23	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0
48 – Nov/ Dec	100	75	5	15	27	4	4	4	4	4	4	4	4	4	0	5	0	0	5	0
49 – Dec	100	85	25	38	42	19	23	4	8	19	15	4	0	0	0	0	0	0	5	0
50 – Dec	95	75	25	31	38	12	4	4	4	4	8	4	4	4	0	0	0	0	0	0
51 – Dec	90	85	15	35	54	12	8	4	4	4	4	4	4	4	0	5	5	5	5	5
52 – Dec	95	90	20	38	58	8	8	4	4	4	4	4	4	4	0	5	5	5	5	5
1 – Jan	95	90	15	38	50	12	12	4	12	12	12	12	8	8	5	5	5	5	5	0
2 – Jan	95	95	20	46	54	15	12	0	8	8	12	4	4	4	5	5	5	5	5	0
3 – Jan	95	90	15	46	58	15	15	0	8	8	8	4	4	4	5	5	5	5	5	5
4 – Jan	95	90	30	50	65	15	19	4	19	19	23	15	8	8	0	0	0	0	10	0
5 – Jan/Feb	100	95	30	46	50	27	15	12	12	12	23	12	4	4	0	5	5	5	5	0
6 – Feb	95	90	35	50	62	19	15	0	8	15	19	12	4	4	0	5	5	5	10	0
7 – Feb	100	100	25	50	65	15	19	4	19	15	19	12	0	0	0	0	0	0	5	0
8 – Feb	100	100	30	62	65	50	46	8	38	46	50	27	19	23	0	5	5	5	19	0
9 – Feb/Mar	100	100	45	69	81	38	27	8	27	31	31	27	12	12	0	0	0	0	14	0
10 – Mar	100	100	35	65	69	19	19	12	19	23	31	19	12	4	0	0	0	0	10	0
11 – Mar	100	100	45	65	77	31	31	15	27	27	31	12	4	4	0	0	0	0	10	0
12 – Mar	100	95	35	77	81	38	31	8	23	31	42	19	0	0	0	0	0	0	10	0
13 – Mar/Apr	100	100	40	69	73	35	35	8	23	23	27	19	0	4	0	0	0	0	19	0
14 – Apr	100	95	40	54	73	42	31	4	27	31	35	19	0	4	0	0	0	0	10	0
15 – Apr	100	95	30	62	77	27	23	0	15	15	23	8	4	4	0	0	0	0	10	0
16 – Apr	100	100	35	50	58	23	12	0	8	23	15	4	0	0	0	0	0	0	5	0
17 – Apr	100	100	20	42	58	15	12	0	12	12	19	0	0	0	0	0	0	0	0	0
18 – Apr/May	100	90	30	35	42	19	12	4	8	12	8	4	0	0	0	0	0	0	0	0
19 – May	100	90	25	31	38	19	12	8	12	15	19	4	0	0	0	0	0	0	10	0
20 – May	100	80	30	38	38	23	23	8	12	12	15	4	0	4	0	0	0	0	5	0
21 – May	100	85	25	31	35	12	12	8	8	12	12	0	0	0	0	0	0	0	0	0
22 – May/Jun	100	85	20	31	42	15	12	0	4	4	4	0	0	0	0	0	0	0	0	0
23 – Jun	95	85	30	19	23	12	4	0	4	4	4	0	0	0	0	0	0	0	0	0
24 – Jun	95	80	15	15	19	4	4	0	0	8	8	0	0	0	0	0	0	0	0	0
25 – Jun	95	80	15	19	23	4	0	0	0	4	4	4	0	0	0	5	0	0	5	0
26 – Jun/Jul	95	75	5	8	8	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0
27 – Jul	95	85	0	4	8	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0
28 – Jul	95	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 – Jul	100	65	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
30 – Jul	100	55	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 – Jul/Aug	95	40	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 – Aug	90	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 – Aug	95	35	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 – Aug	90	45	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 – Aug/Sep	90	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 – Sep	90	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 – Sep	80	20	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 – Sep	80	15	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Freshwater drum

Winter Habitat Used by Fishes in Smithland Pool and Belleville Pool, Ohio River

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Final Combined Project Report

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Executive Summary

Introduction

For many fishes that inhabit large rivers, winter poses a challenge to both age-0 and older life stages. Swimming ability is compromised at low temperatures in many species. Further, energetic condition often declines as food availability declines during winter. Hence, fishes occupying rivers may congregate in warm, low velocity shelters with abundant food to avoid poor growth and survival. If these sites are in proximity to vessel traffic in navigable systems such as the Ohio River, displacement may compromise fish success.

Approach

We conducted a literature review to assess the potential habitat use of several Ohio River fishes during winter. Using predictions generated by this review, we identified general sites in the Smithland Pool (Southern Illinois University Carbondale: SIUC) and Belleville Pool (West Virginia University: WVU) of the Ohio River that may provide winter habitat: artificial, island backwater, tributary, and main channel (about 30 sites per river pool, stratified equally across habitat types). Artificial sites were defined as scours associated with structures in the main channel (e.g., wing dams). Island backwaters were areas between channel borders and islands. Tributaries were sampled near the confluence with the Ohio River. Main channel sites were directly adjacent to or in the main channel. Catch per hour of fish was quantified using variable-depth alternating current (AC) electrofishing (identical units at both institutions) at depths ranging 3-14 m during the winters of 2002 and 2003. This gear was chosen because of its ease of standardization and ability to sample in a variety of river macrohabitats. Further,

fish were expected to aggregate in deep water areas with low flow velocities during cold temperatures. This gear effectively sampled fish in areas difficult to sample with other active gear types. Water quality characteristics that were quantified included dissolved oxygen concentration, secchi depth, temperature, and flow rate. In addition to the coordinated joint effort, each research group collected additional data in other habitats (e.g., island tips, embayments) and with other gears (e.g., gill nets).

Literature Review

The literature revealed that most species require low velocity refuges when temperatures < 4°C. Swimming ability is compromised at these low temperatures. However, overwintering in low velocity backwater habitats that may become hypoxic may also negatively affect winter survival. Species will likely differ in their ability to persist in areas in proximity to the main channel. Channel catfish, a common species in the Ohio River, should be able to tolerate relatively high flows at low temperatures. Conversely, survival of species such as largemouth bass should be compromised if they cannot successfully seek low velocity refuges away from the main channel. Use of habitat by fishes during winter should be affected by trade-offs between swimming ability in the main channel and surviving potentially low oxygen conditions in backwaters.

Site Description

Smithland (river miles: 162-204) and Belleville (river miles: 843-913) Pools of the Ohio River differ in size, elevation, and abiotic characteristics. Each pool is created by lock and dams that maintain a 2.7-m deep (9 foot) navigation channel at low

discharge. Smithland Pool, currently the southernmost impoundment of the Ohio River, is 115 km long with an area of 11,134 ha during normal pool. Belleville Pool, to the north of Smithland Pool and at a higher elevation, is 70-km long with a smaller surface area of 2,850 ha. Island and artificial habitats were much more limited in Belleville than in Smithland Pool. Smithland Pool did not contain the extensive embayment area that was present in Belleville Pool. Depths of sites sampled were somewhat shallower, on average, in Belleville Pool. Artificial sites in Smithland ranged 8-11 m (mean = 9 m). Only one artificial site was sampled by WVU in Belleville Pool. Island backwaters sites ranged 5-8 m (mean=6 m) in Smithland Pool and 2-6 m (mean=5 m) in Belleville Pool. Main channel sites were 6-9 m (mean= 8 m) and 3-9 m (mean=6 m) in Smithland and Belleville Pools, respectively. Tributary habitats ranged 3-8 m (mean = 5 m) in Smithland Pool and 2-9 m (mean = 6 m) in Belleville Pool. WVU included a separate "deep hole" category for distinct, main channel scour holes that ranged 7-14 m (mean = 9 m). These sites were similar in depth and characteristics of many of the main channel sites chosen in Smithland Pool by SIUC.

Winter conditions

Winter conditions differed between Smithland and Belleville Pools during winters 2002 and 2003. Discharge was quite high and variable during both sampling years in Smithland Pool, with river stage frequently increasing by 8-10 m within a few days (see Figure 2-2, Chapter 2). Consequently sampling was often compromised, and we were relegated to sampling during periods of relatively low flow in the pool. In Belleville Pool, discharge was less variable and relatively lower, with stage only increasing by a maximum of 2.5 m relative to base flow (Figure 3-3, Chapter 3). Flow rates quantified in

Belleville Pool during both winters were often higher (reaching or exceeding 1.0 m/s) in main channel sites than in Smithland Pool. This occurred because WVU could sample during periods of moderate discharge, whereas these moderate flow conditions never occurred in Smithland Pool. In both pools, depth-stratified profiles revealed that water chemistry (e.g., dissolved oxygen concentration, conductivity) and temperature did not vary appreciably with depth. During warmer months, dissolved oxygen concentrations in tributaries of Smithland Pool but not Belleville Pool declined below levels (< 4-5mg/L) preferred by fish and other organisms. Unlike Belleville Pool, dissolved oxygen concentrations in Smithland Pool tributaries were typically lower than at other sites associated with the main channel during all sampling sessions. Specific conductance, a factor that affects electrofishing efficiency, differed between pools, with conductivity often being higher in main channel sites of Smithland Pool.

Habitat-specific Conditions

We used multivariate analyses to assess macrohabitat-specific abiotic characteristics during winter including flow, dissolved oxygen, conductivity, and temperature. In Smithland Pool, habitats did separate out with respect to physical conditions, but often not in direct correspondence with our predetermined habitat delineations. Tributaries clustered with respect to low dissolved oxygen concentration, high water clarity (as estimated with secchi readings), and low flow. In Belleville Pool, sites typically did not show specific clustering with respect to the abiotic variables quantified, although tributaries did have consistently lower flow rates. During some winter periods, tributaries were colder than main channel sites in Belleville Pool.

Fish Habitat Use

Species richness (i.e., number of species sampled) differed between Smithland and Belleville Pools during the two sampling winters. In Smithland Pool, a total of 19 species was sampled each year. Species richness was much higher in Belleville Pool, with AC electrofishing generating a total of 28 species. During both years in Smithland Pool, freshwater drum and blue catfish dominated samples, often comprising > 90% of fishes. In Belleville Pool, freshwater drum were often abundant, but channel catfish was the dominant catfish species. These species typically comprised 80% of fishes sampled, with other species such as gizzard shad being important as well.

Winter habitat use by fishes differed between the pools. During both winters in Smithland Pool, catch per unit effort (CPUE; number of fish per hour) was higher in sites adjacent to the main channel (i.e., main channel and artificial) than in tributaries (Table 1). CPUE varied considerably among sites in Belleville Pool, with maximum average catch rates exceeding those in Smithland Pool (Table 1). Catch rates of fish were higher in tributaries in Belleville than in Smithland Pool, with catch rates of fish in Belleville Pool being higher in sites associated with the main channel in 2003 (Table 1).

Species richness in macrohabitats of Smithland Pool varied with abiotic factors during both winters. Both tributary and island backwater sites had high species richness at cold temperatures. Further, species richness in tributaries increased with a slight rise in flow rates. When dissolved oxygen concentrations declined below 5 mg/L in Smithland tributaries (which occurred at warm, late-spring temperatures), fish species richness declined. Small, young freshwater drum were associated with tributary sites during winter in Smithland Pool, suggesting that these areas may provide some refuge for early life stages. In Belleville Pool, high catch rates and richness in tributaries during winter

were likely due to the low flow rates in these macrohabitats. However, when temperatures in these areas declined below 4°C, fish were more abundant in main channel areas, suggesting that fish leave cold water areas to inhabit relatively warmer but higher flow areas in the river. In Belleville Pool, shallow areas with large woody debris were also sampled with DC surface electrofishing, revealing the presence of other fish species not sampled with the variable depth AC gear.

Variable-depth electrofishing was compared with other gear types such as sonar and gill nets. Gill netting conducted by WVU in Belleville Pool revealed low catch rates with species composition similar to that generated by electrofishing. Low catch rates with active gill netting are not unexpected given the cold temperatures and low activity of fishes. Both groups conducted some comparisons between sonar and variable depth electrofishing and found no strong relationships between abundance as estimated by the two gears. A study conducted during winter 2002 in Pool 25, upper Mississippi River by SIUC in collaboration with the Missouri Department of Conservation and the US Army Corps of Engineers, St. Louis District, compared variable depth AC electrofishing with purse seining and trawling behind chevron dikes. AC electrofishing generated similar sizes and species as the other gears, further confirming that this technique provides a relatively clear picture of fish assemblages at depths > 3 m.

Conclusions and Implications

During both winters and in both pools of the Ohio River, fish assemblages and abundance differed among the macrohabitats we identified at the outset. In Smithland Pool, habitats adjacent to the main channel appeared to be important for fish during the winter. Particularly, island backwaters and submerged boulders at the channel border

were areas that contained large aggregations of fish during cold, winter conditions. Deep scours created by artificial structures (e.g., submerged wing dikes) also provided refuge for fish at cold temperatures. Tributary macrohabitats in Smithland Pool only appeared to provide important winter habitat when temperatures were low and when these areas were connected to the main channel. Tributaries in Smithland Pool are often disconnected from the main channel by a shelf of sediment and debris that may inhibit the passage of fish from the main channel. In Belleville Pool, tributaries and an embayment area appeared to play a critical role for wintering fishes. However, these macrohabitats may cool more than the main channel during some winter periods (e.g., as might be expected during a period of snow melt), necessitating the movement of fish into warmer main channel areas. Surface electrofishing of shallow areas adjacent to the main channel revealed that different fish assemblages may be using these areas during winter.

When fish use main channel habitats during winter, they may be subjected to changes in flow as barges move into their proximity. Fish with impaired swimming ability at cold temperatures (e.g., freshwater drum; see Table 1-1, Chapter 1) may be displaced by changes in flow direction and velocity. Preliminary data quantified with an acoustic doppler profiler behind wing dikes of the middle Mississippi River support this supposition. This instrument quantifies both flow velocity and direction at 0.5-m intervals from the surface to the bottom. In our study, we profiled flow at fixed points behind wing dams before, during, and after barges passed (Spier, Braeutigam, and Garvey unpublished data). Although our results are admittedly tentative, we found that flow was relatively low with coherent directionality as barges approached (Figure 1). After barge passage, displacement of water caused flow velocity to increase and an incoherent (i.e., multidirectional) flow pattern to occur (Figure 1). Flow rates continued

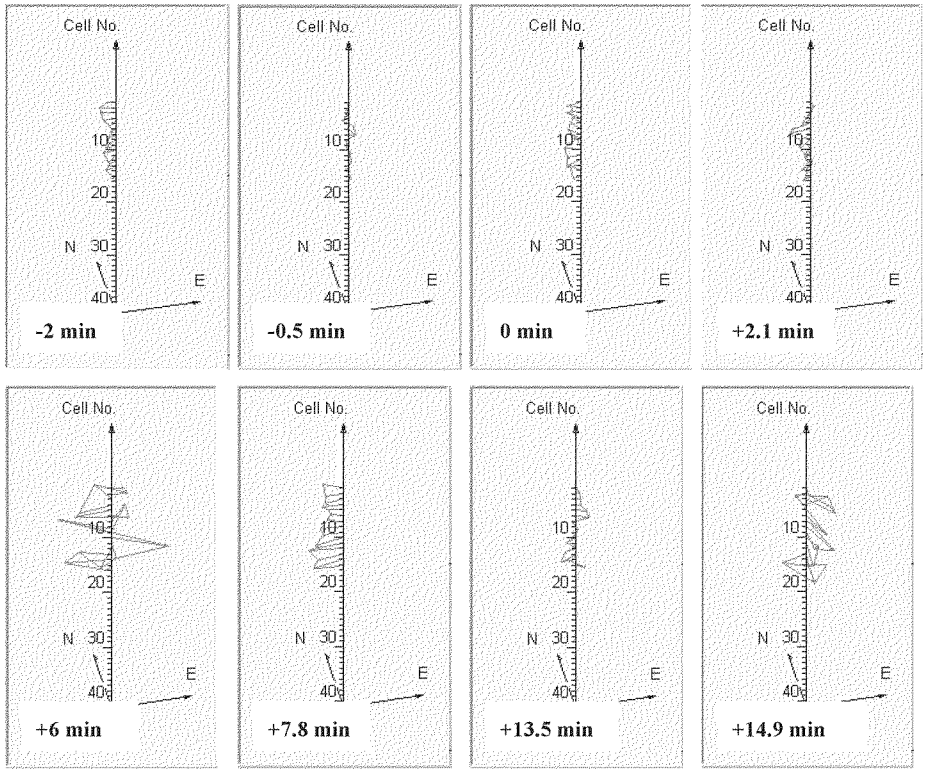
to be affected by barges 15 minutes following passage of the bow (Figure 1). Thus, fish seeking typically low velocity deep water habitats behind river structures may be displaced if low temperatures reduce swimming ability. Again, we will continue to view these results with caution until more data are collected, but the pattern is compelling and is congruent with other studies.

This unique opportunity to conduct parallel research projects in two impounded Ohio River reaches during the same winters has provided insight into the potential effects of anticipated increased navigation on fish assemblages. Tributary habitats are clearly important to wintering fish, and reduced connectivity in Smithland Pool likely compromises the success of many species. Improved connectivity, perhaps through dredging at confluences, may improve winter success of fishes in this pool. Higher species richness and greater tributary use by fishes in Belleville Pool suggest that connectivity may not be problematic in this impounded reach. Many fishes such as commercially important channel and blue catfish use sites adjacent to the main channel in Smithland Pool. Similarly, channel catfish use the main channel in Belleville Pool. Artificial sites such as wing dikes in Smithland Pool create scours that are used by river fishes, although some concern about displacement by barges does persist, requiring further exploration. Island backwater areas appear to be particularly important for fishes during winter. These areas provide flow breaks and are relatively sheltered from barge activity. River habitat management that enhances/maintains accessibility to these areas should be beneficial to wintering fish in the Ohio River.

Table 1. Mean number of fish per hour (CPUE) sampled with variable-depth electrofishing during winters 2002 and 2003 at common macrohabitats sampled in both Smithland Pool and Belleville Pool, Ohio River. * depicts site not sampled. In 2003, only one artificial (wing dam) site was sampled in Belleville Pool.

		Mean number of fish per hour			
Pool	Year	Artificial	Island Backwater	Main Channel	Tributaries
Smithland	2002	85	21	113	41
	2003	41	51	62	7
Belleville	2002	*	5	4	115
	2003	203	10	27	70

Figure 1. Flow velocity and vector profile behind a wing dam in the Mississippi River during December 2003. Each cell is 0.5-m in depth. The site was about 7.5-m deep. Times on the graph depict when the bow of a barge was approaching (negative), at (zero), and past (positive) the wing dam site. Direction of vectors represents the direction of flow (the thalweg was west of the profiler). Magnitude of flow is estimated by the length of the vectors.



General Introduction

Winter is a critical period in which high mortality occurs in fishes (Oliver et al. 1979; Cunjak 1996; Garvey et al. 1998). Many temperate fishes undergo a torpor-like state when exposed to prolonged cold temperatures and short days (Crawshaw 1984) and, as such, may be highly susceptible to vessel-passage induced displacement from velocity shelters. Because the Ohio River extends through mid-temperate latitudes, inter-annual variability in winter temperature may translate to highly variable responses of fish populations to acute abiotic perturbations (see Garvey et al. 1998) such as changes in flow velocity and flow direction with navigation. Laboratory (Sheehan et al. 1990; 2000a) and field studies (Sheehan et al. 1990b; Logsdon 1993; Johnson et al. 1998) showed that a number of Mississippi River fishes overwinter in stratified backwater areas, when they have access to them, or in low velocity areas in channels. Relatively small (0.08 to 0.16 $m \cdot s^{-1}$) velocity changes, such as those that can be induced by vessels, can displace small bluegill and channel catfish from low velocity habitats when water temperatures are low (1 to 4 ^{o}C) (Sheehan et al. 2000b). If fish are displaced into flowing channels at such temperatures, mortality will probably increase (Bodensteiner and Lewis 1994; Sheehan et al. 2000a).

Fish are an important economic and ecological component of the Ohio River ecosystem. Understanding how abiotic characteristics (e.g., latitude, channel morphometry, depth) regulate winter habitat use of critical fish species is the primary objective of this research. Habitat characteristics affecting winter survival of fish may well vary locally among adjacent pools as well as geographically between the upper and lower reaches of the Ohio River. We have completed an intensive literature review

(Chapter 1), quantifying winter habitat associations in fishes commonly found in the Ohio River. We also have completed a 2-year, winter survey of a lower (Smithland; SIUC, Chapter 2) and upper (Belleville; WVU, Chapter 3) pool of the Ohio River.

The literature review and field reconnaissance generated *a priori* expectations about habitat use of fish during winter (see Chapter 1). In Chapters 2 and 3, we present results from an intensive winter field effort conducted during winters 2002 and 2003 to fill in the gaps about winter habitat associations of common Ohio River fishes and their potential responses to winter navigation.

Chapter 1 – Literature Review

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Winter often is a critical period influencing the condition and survival of fishes in marine (Sogard 1997; Schultz and Conover 1997; Schultz et al. 1998; Hurst et al. 2000) and freshwater (Hubbs and Carlander 1935; Aggus and Elliott 1975; Gutreuter and Anderson 1985; Cunjak 1988; Garvey et al. 1998) temperate-zone systems. Winter mortality is typically highest for young-of-year (YOY) fish, with survival probability increasing with increasing body size (e.g., Toneys and Coble 1979; Ludsin and DeVries 1997; Garvey et al. 1998; Foy and Paul 1999). Thus, the extent of first-year growth, fall body size, and winter severity may regulate year-class strength in some species and systems. For age-0 fish as well as older life stages, rivers can be particularly challenging environments in which to reside during winter because a host of abiotic characteristics limit survival and growth (Sheehan et al. 1990; Bodensteiner and Lewis 1992; Cunjak 1996; Jakober et al. 1998). As such, fish must choose the most benign habitat available during winter to increase their probability of surviving. In the mainstem Ohio River, the quantity and availability of winter refuge may well determine the relative survival and abundance of resident fish populations. The ability of these habitats to provide refuge from vessel-induced displacement is essential, given the anticipated increases in barge traffic in the Ohio River. To determine what habitat-specific factors influence winter growth and survival of fish in the mainstem Ohio River, we reviewed > 300 articles pertaining to the winter physiology and ecology of fish, focusing on fishes commonly occurring throughout this system. Articles were obtained using standard abstracting services such as Biological Abstracts, Science Citation Index, and Aquatic Sciences and

Fisheries Abstracts, Dissertation Abstracts, and the U.S. Fish and Wildlife Reference System. Major reviews such as Carlander's Handbook of Freshwater Fishery Biology, Volumes 1-3 provided a source for early research articles (Carlander 1968, 1977, 1996).

Mechanisms influencing the Overwinter Condition and Survival of Riverine Fish

Overview

Several mechanisms may work either exclusively or in concert to affect the growth and survival of cool- and warm-water riverine fishes during winter. Failure to tolerate cold temperatures, flowing water, low food availability, or low dissolved oxygen concentrations can negatively affect fish throughout the Ohio River. The relative importance of these factors may vary as a function of reach-specific factors including (but not limited to) latitude, winter severity, within-pool location, and river morphometry.

Two major overwintering habitat types - main channel and backwater - can be categorized within the Ohio River, although much variation exists within each (e.g., Sheehan et al 1990; Logsdon 1993). Main channel reaches are oxygen-saturated with temperatures that likely differ among latitudes. Mainstems of northern river reaches (e.g., upper Mississippi River) are typically < 1°C during winter (Sheehan et al. 1990; Johnson et al. 1998). In contrast, main channel water temperatures in southern reaches may be warmer and more variable. For example, temperatures below the Smithland Pool of the lower Ohio River only declined below 2°C for about 1.5 weeks during one of three winters (Shawnee Fossil Fuel Electric Power Utility). Among years, water temperatures varied between 4 and 9°C in early January at this site (also see Chapter 2 for 2002). Hence, fish residing at different latitudes within the main channel may be confronted by fundamentally different temperature-dependent challenges during winter that vary among

years. Flow velocity within the main channel during winter is typically greater than that tolerated by many fish species at cold temperatures (see **Species Requirements**). However, fish may use various structures within the channel such as wing dams that provide relatively deep, low-velocity flow breaks (Heese and Newcomb 1982; Logsdon 1993), although these areas may be susceptible to vessel-induced displacement by barges (Todd et al. 1989). Low-flow sites connected to the main channel (e.g., backwaters) may provide refuge for fish during winter (Greenback 1956; Sheehan et al. 1990; Knights et al. 1995; Raibley et al. 1997). Temperatures stratify in these sites, providing elevated thermal habitat near the bottom (Sheehan et al. 1990; Johnson et al. 1998). However, dissolved oxygen can decline in these areas (Sheehan et al. 1990). In the following sections, we review how temperature, flow, energetic condition, and dissolved oxygen affect Ohio River fishes during winter. We then review winter habitat requirements of several species commonly found in this system.

Cold tolerance

Environmental temperatures dramatically affect physiological processes in fishes (Love 1980). Much research has been devoted to determining upper lethal thermal limits of fish (Hart 1952; Cvancara et al. 1977; Spotila et al. 1979). Lower lethal limits have received much less attention, although the lower thermal tolerances of many species likely exceed temperatures that occur in temperate rivers during winter (see **Species Requirements**). Researchers also have sought to determine the final thermal preferenda of temperate species (Reuter and Herdendorf 1974; Cherry et al. 1975; Kelsch and Neill 1990); preferred temperatures are typically absent during winter (Sheehan et al. 1990). Interestingly, if preferred temperatures become available to temperate species acclimated

to winter temperatures, they may seek them, even if the temperature difference is great (e.g., $\geq 10^{o}$C; Kelsch and Neill 1990). During winter, species may track even slight temperature differences, seeking the warmest temperatures available (see Chapter 2). Residing at cold temperatures is clearly not advantageous for most species in the Ohio River.

Cold temperatures may compromise the growth and survival of fish for several reasons. Typical winter temperatures are well below the maximum metabolic scope (Fry 1947) of Ohio River fishes. As such, consumption and activity rates are limited, greatly reducing growth potential. Rapid declines in temperature can cause cold shock, a condition in which fish lose equilibrium (Cichra et al. 1982) and may become susceptible to predators (Coutant et al 1974). In rivers, fish undergoing cold shock may be displaced into the open channel, with little opportunity to regain position in low velocity habitats (Lewis and Bodensteiner 1994; Sheehan et al. 2000). Although river temperatures may supercool to -0.1 C (Devik 1944), fish will not freeze because their internal salinity depresses their freezing point between -0.5 and -0.65 C (DeVries 1971). Physiological problems associated with declining temperature rather than freezing are apparently responsible for cold shock and associated mortality.

Cold tolerance may depend on body size (Edsall and Colby 1970), leading to the patterns of size-dependent winter survival documented for many fish species. Although all Ohio River fish species are considered pokilothermic, core body temperatures typically exceed those of the environment, with large fish generating as much as 0.5^{o}C more heat than small fish (Stevens and Fry 1970; 1976). When environmental temperatures decline abruptly, internal body temperature of small fish declines to a new, lower stable state much more rapidly (within 10 minutes) than that of large fish (2.5

hours for 4 kg fish; Spigarelli et al. 1974). Although the evidence is somewhat tenuous, the morphology of species may affect temperature tolerance, whereby laterally compressed species such as gizzard shad and white bass are less tolerant to temperature shock than heavy bodied species such as ictalurids and common carp (Reuter and Herdendorf 1976). Hence, small, laterally compressed fish species may be more susceptible and respond more rapidly to the negative physiological effects of extremely low temperatures in the Ohio River.

Because temperature strongly affects growth and survival, distribution of fishes in aquatic ecosystems is often associated with temperatures near or at their thermal preferenda (Crowder et al. 1981). In winter, we predict that the availability of "warm" ($\geq 4^{\circ}C$) water will be a primary factor affecting habitat choice in the Ohio River, regardless of river reach and latitude. Backwaters in the Upper Mississippi River provide such elevated thermal refuges. Indeed telemetry studies (e.g., Pitlo 1987; Knights et al. 1995; Raibley et al. 1997) and active and passive sampling efforts (Sheehan et al. 1990) during winter have demonstrated robust use of these habitats by riverine fish. Other structures such as cobble may elevate microhabitat temperatures sufficiently to facilitate survival (Smith and Griffith 1994). Warm effluent from thermal power generation may also harbor high densities of fish within localized points in the Ohio River (see Adams et al. 1982), although these areas can cause mortality due to cold shock if thermal effluent subsides. The Ohio River extends across about 3.5° N latitude, with the northern reach of the river receiving water from the northern Allegheny River and the relatively mountainous Monongahela River. Hence, water flowing into the northern Ohio River should be substantially colder than that in the south, which often is $>4^{\circ}C$. We may surmise that seasonal and regional differences in winter temperature along the river

influence the duration and intensity of thermal refuge use, with relatively shorter stays occurring in the southern reach.

Swimming

A common response of many cold-, cool-, and warm-water fishes is to seek low velocity habitat during winter months. Although cool- or cold-water fishes may swim generally well at cool temperatures, swimming to maintain position can cause them to deplete limited energy reserves during winter (Cunjak 1987). Cederholm et al. (1987) found that increasing the quantity of large woody debris in streams created flow breaks, improving survival of coho salmon during winter. Young salmon seek low-flow, off-channel lentic habitats during winter (Bryant 1988), apparently to avoid the energetic costs of maintaining position. Warm-water fish attempting to maintain position at winter water temperatures and flows within their swimming tolerance also may incur energetic costs that may cause depletion of energy reserves and mortality.

Swimming ability of warm-water fishes can be impaired during winter (Sheehan et al. 1990). Species such as smallmouth and largemouth bass acclimated to winter photoperiods and temperatures do have improved swimming performance (Larimore and Duever 1968; Kolok 1991), but these adaptations are insufficient if flow rates exceed a critical point or temperatures decline below a critical minimum. Sheehan et al. (1990) and Logsdon (1993) determined experimentally that swimming ability of several fish species was compromised at temperatures $< 4^{\circ}C$, although the degree of responses differed among species. Swimming ability of YOY walleye, a cool-water species, did not decline with declining temperature (see **Species Requirements**). Conversely, the swimming ability of warm-water YOY channel catfish, largemouth bass, and bluegill

declined with declining temperature. Within the limited range of lengths used, size did not affect swimming ability in any of the species tested at 0°C (Sheehan et al. 1990). At higher temperatures, swimming ability increased with increasing size in several of the species (Sheehan et al. 1990). Failure to maintain position due to impaired swimming ability at low temperatures may cause fish to become displaced into the main channel (Bodensteiner and Lewis 1994; Sheehan et al. 2000), with the same potentially lethal consequences as cold shock. Improved swimming ability with increasing size may well mean that variable growth and first-year size affects patterns of survival of warmwater fishes in the Ohio River.

Habitat selection of Ohio River fishes during winter should depend on the relative effect of flow and temperature. If flow is low in the main channel (< 1 cm/s), these fish may not require low-velocity refuges (Johnson et al. 1998). At higher flow velocities, responses likely depend on species-specific tolerances to low temperatures. If temperatures vary along a gradient within the river, we may expect to see different fish responses (e.g., duration of refuge use) depending on river location. Under relatively mild winter temperatures ($\geq 4^{\circ}C$) that occur during some years in the lower Ohio River, many species may remain active but incur energetic costs of maintaining position, similar to cold-water fish at higher latitudes. These warm-water fish may seek low-flow velocity habitat not to reduce the negative effects of cold, but to reduce energetic costs. Clearly, these mechanisms need to be explored for fish assemblages in mid-latitude rivers such as the Ohio River.

Energy depletion

At temperate latitudes, ecosystem production declines during winter as

temperatures and day length decline. As such, food availability for most fishes declines, requiring that energy reserves be used to offset metabolic costs (Thompson et al. 1991; Miranda and Hubbard 1994a; Ludsin and DeVries 1997; Wright et al. 1999; Fullerton et al. 2000). Within populations of warm-water species, some individuals undergo an inactive, torpor-like state during winter (Sullivan 1984; Crawshaw 1984), minimizing metabolic costs but also eliminating energy intake. Other individuals within species may forage intermittently during winter at "intermediate" temperatures (e.g., 5-6°C for some species; Sullivan 1984; Garvey et al. 1998; see Chapter 2). In an overwinter pool experiment in which YOY largemouth bass were presented with invertebrate prey, some fish fed with variable success (i.e., some grew and others lost weight), whereas others did not feed or foraged rarely during the entire winter (Miccuci et al. in press). On average, non-feeding individuals lost less wet mass than those that foraged unsuccessfully (i.e., lost mass) in this experiment. If these variable responses to food availability during winter are typical within species, they may affect patterns of relative condition and survival in riverine systems at "intermediate" (> 4°C) temperatures.

The negative relationship between length and survival of YOY fishes during winter at temperate latitudes has often been attributed to size-specific differences in energy reserve depletion (Oliver et al. 1979; Miranda and Hubbard 1994a; Ludsin and DeVries 1997). Small fish typically have higher mass-specific metabolic rates and lower energy reserves than large counterparts, increasing their probability of depleting energy stores and dying when food is scarce during winter. This has been shown for a variety of species typically found in the Ohio River (see **Species Requirements**). However, patterns of size-selective mortality can vary among populations within a species (Garvey et al. 1998), suggesting that system-specific factors such as food availability (Fullerton et

al. 2000), temperature (Toneys and Coble 1980; Sheehan et al. 1990), and perhaps size-selective predation (Green 1982; Miranda and Hubbard 1994b; Miranda and Pugh 1997; Garvey et al. 1998) are important.

The cause of mortality at cold temperatures may be due to osmoregulatory dysfunction (Oliver 1977; Toneys and Coble 1980; Bodensteiner and Lewis 1992) and high associated energetic costs (Toneys and Coble 1980). Because of potential size-dependent differences in cold tolerance and energy depletion, small fish may suffer greater mortality than large counterparts as a function of this mechanism. Bodensteiner and Lewis (1992) found that freshwater drum residing in 4°C backwater habitats of the upper Mississippi River had higher plasma osomolalities than those in 0-1°C channel habitats, supporting the hypothesis that cold temperatures challenge water balance in the field. However, size-dependent energy depletion of largemouth bass, green sunfish, yellow perch, and brook trout at winter temperatures did not differ under freshwater and relatively isosmotic conditions (Toneys and Coble 1980). Although cold temperatures incur negative osmoregulatory effects on both small and large fish, they apparently do not affect patterns of energy depletion in these species.

How winter affects growth and survival of fish may also depend on the interactions among winter temperature, duration, body size, and food availability. In northern rivers (perhaps including the northern reach of the Ohio River), winter is long and cold. Conversely, winter duration is considerably shorter in southern systems. Fullerton et al. (2000) simulated northern (45°N) and middle (40°N) latitude winter conditions in experiments to determine how YOY largemouth bass respond to winter temperatures, photoperiods, and food availability. Largemouth bass that were fed fish prey during winter lost and maintained weight in the northern and middle-latitude

winters, respectively. Mass-balance bioenergetics models for largemouth bass predicted much greater loss of weight than occurred in either winter, suggesting that the fish reduced metabolic costs more than experimentally derived metabolic relationships predicted (Wright et al. 1999). Starved largemouth bass lost similar weight between the long, northern, simulated winter and the short, middle-latitude one (Fullerton et al. 2000). Apparently, the energetic costs of winter fasting do not increase with increasing latitude, because declining temperature-dependent metabolic costs offset the increased duration of starvation. We predict that winter food availability may differentially affect the condition and growth of largemouth bass and perhaps other fish with similar physiological/life history adaptations in northern and southern reaches of the Ohio River.

Oxygen

Declining oxygen during winter has long been recognized as an important factor structuring fish assemblages in north temperate lakes (Petrosky and Magnuson 1973; Klinger et al. 1982; Tonn and Pazkowski 1986). Species-specific tolerances for low oxygen and access to oxygen refuge (e.g., streams), determine the intensity of winterkill within these systems. Although oxygen is typically abundant in the main channel of rivers, oxygen availability in backwater refuges may decline when ice forms (Gent et al. 1995; Knights et al. 1995) or oxygen-poor groundwater inundates (Sheehan et al. 1990). Because 4°C water at the bottom of these systems may overlap with oxygen-poor conditions near the profundal zone due to high biological oxygen demand, fish may be restricted to cooler water higher in the water column. If the total water-column oxygen concentration declines below the tolerances of resident fish, telemetry movement studies have shown that they will leave these backwater habitats until oxygen concentrations

return to tolerable quantities (e.g., Gent et al. 1995).

By understanding the thermal- and oxygen-tolerance limits of riverine fish, we may improve backwater habitat during winter. Dissolved oxygen concentrations can be increased in backwaters by introducing water from the main channel through culverts (Johnson et al. 1998). This approach worked generally well in the Finger Lakes, a system of six backwaters of the upper Mississippi River, although stratification created by the influx of cold mainstem water limited the quantity of thermal habitat (Johnson et al. 1998). In the Ohio River, the availability and quality of backwater habitat also may be critical for overwintering fishes. Careful consideration of temporal variation in oxygen and temperature within these habitats will be necessary to determine their contribution to fish assemblages in this system. From this, we will be able to determine if management of oxygen within these habitats is necessary to improve overwintering success.

Synthesis

The Ohio River is a complex system with channel characteristics, tributaries, embayments, backwaters, and winter conditions etc. that vary among pools. How winter conditions affect fish assemblages depends to a great degree on the behavioral and physiological responses of individual species and the availability of critical refuge habitat within each segment. This habitat, typically defined as $\geq 4^{\circ}C$, low flow, and high oxygen, may vary in utility, depending on winter conditions along a latitudinal gradient within the river. Fish in northern reaches of the Ohio River may seek these refuge habitats primarily to avoid channel temperatures $< 4^{\circ}C$ that compromise swimming ability and osmoregulatory function. Counterparts in lower reaches typically do not experience such low temperatures. However, given low food availability and energetic costs of

maintaining position during winter, fish may still seek low velocity habitats to avoid energy depletion. The critical importance of winter habitat in a northern and southern pool of the Ohio River was assessed during winter 2001-2002 with a coordinated field effort between West Virginia University and Southern Illinois University. Because several of these habitats are vulnerable to water displacement by barges, navigation in the Ohio River during winter may be a critical determinant of fish assemblage structure.

Species Requirements

Overview

In this section, we review how several commonly occurring Ohio River species respond to winter conditions (see Table 1-1). These responses plus published surveys of winter habitat use provide insight into potential habitat use/requirements in the Ohio River. For some species (e.g., largemouth bass), a fair amount of information is available about physiological and behavioral responses to winter conditions. Scant information exists for others. This information will be used to generate generic- or species-specific predictions for winter habitat use of fish in both the northern and southern reaches of the Ohio River.

Largemouth bass (Micropterus salmoides)

Largemouth bass from northern populations (*M. salmoides salmoides*) acclimated to winter temperatures can tolerate 0°C (Garvey et al. 1998; Sheehan et al. 2000). Sheehan et al. (1990) quantified higher mortality of YOY largemouth bass at 0°C (40%) than at 4°C. However, in outdoor pool experiments in Ohio under a winter photocycle and temperatures, mortality was often 0%, even though temperatures occasionally

reached 0°C (Garvey et al. 1998). Both the duration of exposure and the rate of cooling may affect tolerance to temperatures < 4°C. The Florida subspecies of largemouth bass (*M. salmoides floridanus*) cannot tolerate temperatures < 4°C (Isely et al. 1987; Garvey et al. 1998), and likely cannot persist at the latitudes that the Ohio River spans.

Largemouth bass swimming ability declines with declining temperature. Individuals were placed in a variable-velocity swimming tunnel in which flow velocity was increased by 10 cm/s every 10 minutes (Sheehan et al. 1990). Mean swimming duration declined from 8.81 minutes to 0.63 minutes at 4 °C and 0°C, respectively. Mean swimming duration did not differ between 11 °C and 4°C, suggesting that the ability for largemouth bass to maintain position in main channel habitat is primarily compromised at temperatures < 4°C. Thus, we should only expect this species to require low velocity shelters when temperatures decline below this threshold. Swimming performance increased with body size at temperatures ≥ 4°C (Sheehan et al. 1990).

Some individual largemouth bass will forage actively during winter when temperatures are ≥ 6°C (Micucci et al. 2003). Below this temperature, feeding appears to occur very rarely (Fullerton et al. 2000). At latitudes encompassing the Ohio River, largemouth bass will forage and grow when food is highly abundant during winter (Garvey et al. 1998). However, it is more likely that food will be scarce and energy reserves will be used to offset winter fasting (Ludsin and DeVries 1997). Although some studies have demonstrated that small largemouth bass exhaust energy reserves more rapidly than large counterparts (Miranda and Hubbard 1994a), others have not (Garvey et al. 1998). We predict that largemouth bass will forage rarely during winter in the Ohio River. Rather, they will seek low velocity habitats in which energy costs are minimized.

At warm temperatures (> 20°C), largemouth bass are unable to tolerate oxygen

concentrations below 1.5 ppm (Moss and Scott 1961) and will avoid these areas (Whitmore et al. 1960). Minimum oxygen concentrations at winter temperatures are lower (0.5-1 ppm). However, this species is quite susceptible to winterkill in lakes, suggesting that prolonged exposure to these or lower oxygen concentrations will eliminate them. Therefore, we predict that largemouth bass will occur at high densities in areas of high oxygen concentrations during winter.

Both surveys and telemetry demonstrate that largemouth bass seek backwater habitats in the upper Mississippi River, likely to exploit warm temperatures (Raibley et al 1997; Sheehan et al. 1990). Largemouth bass and smallmouth bass may school under winter conditions (Townsend 1916). If oxygen concentrations decline in backwater habitats during winter, radio-telemetry has demonstrated that they will depart and not return until concentrations rise (Gent et al. 1995). Thus, the avoidance of low oxygen likely is a major factor influencing movement of largemouth basin the Ohio River during winter.

Channel catfish (Ictalurus punctatus)

Channel catfish acclimated to winter conditions can tolerate temperatures reaching 0°C (Sheehan et al. 1990). When acclimated to warmer temperatures, and placed in cold (4°C) water, this species will experience cold shock (Smith and Griffith 1994). Swimming ability declined with declining temperature (Sheehan et al. 1990), although to a lesser extent than for other species (see above for largemouth bass). Mean swimming time declined from 11.5 minutes to 3.0 minutes when temperatures declined from 4°C to 0°C (Sheehan et al. 1990). Apparently, channel catfish are better adapted than several other warm-water species at maintaining position at moderate flows in

riverine habitats. We might expect this species to have moderately flexible habitat use in the Ohio River.

Channel catfish can tolerate oxygen concentrations of $\geq$ 1 ppm at warm (>20°C) temperatures (Moss and Scott 1961). Minimum lethal oxygen limits likely decline at cold temperatures, although this species is subject to winterkill when oxygen is depleted. Growth continued during winter in the Mississippi River (McInerny and Held 1995), suggesting that foraging and growth may continue during winter.

Channel catfish will congregate in low flow areas such as backwater habitats (Sheehan et al. 1990) and deep-water scour holes (Heese and Newcomb 1982; Newcomb 1989; Logsdon 1993) during winter. They also will use main channel flow breaks such as cobble or debris (Hawkinson 1980, Lubinski 1985). Their tolerance of cold temperatures and moderate flow should allow them to use the main channel Ohio River during winter. We predict that this species has a more cosmopolitan distribution in the Ohio River during winter by not being restricted solely to backwater habitats and continuing to forage. However, individuals in main channel flow breaks or scour holes may be more susceptible to vessel-induced displacement (Todd et al. 1989).

Black crappie (Pomoxis nigromaculatus)

Black crappie tolerate 0°C when acclimated to winter conditions (Sheehan et al. 1990). This species swims poorly at all winter temperatures, with mean swimming durations of 1.4 and 1.3 minutes at 4°C and 0°C (Sheehan et al. 1990). As such, it appears that black crappie is not well adapted for maintaining position in current during winter and must seek low flow areas. In support of this, Knight et al. (1995) found that radio-tagged black crappie in backwaters of the upper Mississippi River always sought

water velocities < 1 cm/s. Also, this species always remained in areas of > 2 ppm oxygen, even if this required relocating to lower water temperatures (Knight et al. 1995). Fluctuating oxygen concentrations (1.8 -4.1 ppm) during experimental winter conditions prevented spawning of black crappie relative to those at higher fluctuating oxygen concentrations (Carlson and Herman 1979). Apparently, high oxygen concentrations and low flow are higher priority characteristics for winter habitat than temperatures $\geq 4^{\circ}C$. Both black and white crappie cease feeding at temperatures < $10^{\circ}C$ (Mathur 1972; McInerny and Held 1995); white crappie schools during winter (Hancock 1954). Although information is less complete than that for other species, we predict that black and white crappie are restricted to low-flow, high-oxygen habitats in the Ohio River during winter across a wide range of temperatures.

Walleye (Stizostedion vitreum)

Walleye acclimated to winter conditions suffered 25% mortality at $0^{\circ}C$ in cold tolerance experiments (Sheehan et al. 1990). Mortality was negligible at $4^{\circ}C$. Walleye in outdoor pool experiments during winter in Ohio experienced occasional $0^{\circ}C$ temperatures and exhibited no mortality (Kershner 1998). Apparently, this species can tolerate the extreme cold temperatures that occur in river sections. Walleye swimming performance was strong at all winter temperatures in a swimming tunnel experiment (Sheehan et al. 1990). Mean swimming durations were 13.9 and 12.4 minutes at $4^{\circ}C$ and $0^{\circ}C$, respectively. Hence, this species is well adapted to maintaining position in flowing water during winter.

Walleye appear to have high oxygen requirement relative to other co-occurring riverine species. At warm temperatures (>$20^{\circ}C$), walleye begin to experience stress at 2

ppm oxygen and mortality at 1.6 ppm (Moss and Scott 1961). Under winter conditions, walleye seek oxygen-rich water (Ager 1976; Sheehan et al. 1990; Coon 1998). Walleye forage actively during winter (Ager 1976; Kershner 1998). In one telemetry study in the Cedar River, Iowa, walleye were usually active in deep backwater areas at temperatures > 2.8°C (Paramagian 1989). Available forage in the fall may improve winter condition and facilitate spring spawning success of walleye (Madenjian et al. 1996).

Small YOY walleye suffered higher mortality than large individuals in some systems (Joy 1975), but not in others (Copeland and Carline 1998). Although cannibalism has been suggested to contribute to these patterns of mortality (Forney 1976), Joy (1975) found no evidence of this mechanism in diets of adult walleye during winter. Hence, size-dependent energy depletion was implicated (Joy 1975). However, Copeland and Carline (1998) found no linkage between lipid depletion and overwinter mortality in laboratory experiments and Pennsylvania lakes. YOY saugeye experienced no size-selective overwinter mortality in Ohio reservoirs (Donovan et al. 1998).

Walleye and perhaps sauger should tolerate relatively high flow rates and temperatures in the Ohio River. However, we predict that *Stizostedion* spp. will avoid habitats with moderate to low oxygen concentrations. At the temperatures common to the southern extent of the Ohio River, walleye and sauger may well remain active for most of the winter.

Bluegill (Lepomis macrochirus)

Bluegill are intolerant of the cold temperatures that may occur in the main channel of rivers during winter (Sheehan et al. 1990). In cold tolerance experiments, bluegill survival was high at 4°C but declined to 44% at 0°C (Sheehan et al. 1990).

Bluegill swimming performance declined significantly with declining temperature, from 5.6- to 0.3-minute mean duration at 4°C and 0°C (Sheehan et al. 1990). Lower lethal oxygen concentrations for bluegill acclimated to winter conditions vary from 0.5-3.6 ppm (Cooper and Washburn 1949; Petrosky and Magnuson 1974). This species is relatively susceptible to winterkill in north temperate lakes (Pertrosky and Magnuson 1974; Tonn et al. 1980).

Although foraging activity of this species has been documented under the ice (Moffett and Hunt 1943), telemetry studies in eastern Tennessee demonstrated that activity is low for this species during winter (Gatz and Adams 1984). If foraging does occur, it is apparently insufficient for growth because several field studies have demonstrated that energy reserves are depleted in a size-dependent fashion in bluegill populations (Bulow et al. 1991; Booth and Keast 1986; Cargnelli and Gross 1997). Further, growth increments on otoliths decline dramatically as temperatures decline in fall (Garvey et al. in press). In YOY bluegill, mortality apparently does increase with declining body size during winter in some systems (Cargnelli and Gross 1996; Garvey et al. in press) but not others (Toneys and Coble 1979). Bluegill occupying shallow water during winter may be highly susceptible to wading shorebird predation (Glahn et al. 1998).

Bluegill must seek backwater habitat with 4°C, low flows, and moderately high oxygen during winter in the Ohio River (see Knights et al. 1995). Apparently, if these habitat requirements are not met, high mortality will occur, as it did in the upper Mississippi River (Bodensteiner and Lewis 1994).

White bass (Morone chrysops) and congeners

Very little information is available about the physiological requirements of white bass during winter. A congener, white perch, that is currently not present in the Ohio River, cannot tolerate temperatures $\leq 2.5^{\circ}C$, with greater mortality occurring in small YOY individuals (Johnson and Evans 1990, 1991). Survival is high for white perch at $4^{\circ}C$, when food is available (Johnson and Evans 1990, 1991). Striped bass, another congener, persists at cold temperatures typically found in river main channels during winter (Hurst et al. 2000; also see Harrell et al. 1988). Although white bass are found as far north as Lake Erie (Barans and Tubb 1973), they appear to have strong thermal preferences, actively seeking warm-water effluent from power plants during winter (Schneider et al. 1977) or areas of greatest temperature under natural winter conditions (Barans and Tubb 1973). During winter, white bass tend to move to deeper, offshore areas in lakes (Beck and Willis 2000) and occupy backwater habitats in the Mississippi River (Sheehan et al. 1990). Growth ceased in white bass when temperatures declined below $18^{\circ}C$ in Navigation Pool 9 of the Mississippi River (McInerny and Held 1995). Taken in concert, this limited information suggests that white bass should become relatively inactive and seek warm-water refuges during winter in the Ohio River.

Freshwater Drum (Aplodinotus grunniens)

Freshwater drum is widely distributed throughout North America and reaches high abundances in river ecosystems (Scott and Crossman 1973; Braaten and Guy 1999). Thus, we may expect that this species tolerates a host of winter conditions to persist so widely. In a laboratory experiment, freshwater drum held at $1^{\circ}C$ and $5^{\circ}C$ experienced higher mortality than those at $10^{\circ}C$ (Bodensteiner and Lewis 1992). When temperatures

declined to 0°C, these fish lost equilibrium. Freshwater drum at cold temperatures were less able to maintain osmotic balance than those at relatively warmer ones (Bodensteiner and Lewis 1992). In the Mississippi River, freshwater drum occupy deep water scour holes (Heese and Newcomb 1982; Logsdon 1993) or backwaters, apparently to exploit temperatures ≥ 4°C, low velocity, and high oxygen concentrations. If these conditions are not met in the Ohio River, high mortality may occur as was observed in the Mississippi River (Bodensteiner and Lewis 1994). Freshwater drum apparently cease foraging and growth at < 10°C (McInerny and Held 1995).

Green sunfish (Lepomis cyanellus)

Green sunfish are a common member of river fish assemblages. However, Sheehan et al. (1990) found that this species suffered high mortality at ≤ 4°C. Presumably, this species must search for > 4°C water and remain inactive to persist during winter. Although field information is limited, winter survival of YOY green sunfish appears to be unrelated to size (Toneys and Coble 1979) or osmoregulatory dysfunction (Toneys and Coble 1980). This species is found in backwaters of the Mississippi River (Sheehan et al. 1990) and is likely restricted to these habitats during winter in the Ohio River as well.

Other Ohio River species

Gizzard shad *Dorosoma cepedianum* are common and abundant in Ohio River fish assemblages. This species typically is found in river backwaters (Sheehan et al. 1990; Bodensteiner and Lewis 1994) and scour holes associated with main channel flow breaks (Logsdon 1993) during winter. This species is quite susceptible to cold shock,

with high mortality occurring in many populations during winter months (Miller 1960; Walburg 1964). This species stores energy as fat in fall (Pierce et al. 1980), with a subsequent decline in stores through winter. The abundance of gizzard shad in fall and during winter can affect survival (Adams et al. 1982) and reproductive success (Madenjian et al. 1996) of sportfish during winter. In our view, gizzard shad should be an important component of Ohio River food webs, with survival in backwater habitats potentially affecting the success of piscivores.

Large cyprinid species such as river carpsucker (*Carpiodes carpio*) and common carp (*Cyprinus carpio*) overwinter in deep scour holes (Heese and Newcomb 1982) and backwaters (Sheehan et al. 1990) of rivers. The minimum lethal temperature of common carp is 0.7°C (Bardach and Berstein 1954), suggesting that this species has broad tolerance to winter temperatures in rivers. Common carp can remain relatively active during winter, when attempting to avoid ice or high flow velocities (Brown et al. 2000). We predict that common carp will occupy a variety of winter habitats both in the main channel and backwaters of the Ohio River.

Although information about overwintering shovelnose sturgeon (*Scaphirhynchus platorynchus)* is scarce, shortnose sturgeon (*Acipenser brevirostrum*) remain in areas of reduced flow in the main channel during winter (Moser and Ross 1995), presumably to reduce energetic costs of maintaining position (Kynard et al. 2000). Activity during winter varies for this species from relatively high in the Lower Cape Fear River, North Carolina (Moser and Ross 1995) to low in two Massachussetts rivers (Kynard et al. 2000). Paddlefish (*Polyodon spathula*) appear to use main channel habitats of the lower Alabama River during winter (Hoxmeier and DeVries 1997). Tagged paddlefish moved between lakes and tributaries in the Lower Cumberland and Tennessee Rivers, Kentucky

(Timmons and Hughbanks 2000). During winter in Alabama and Texas, diets of paddlefish included copepods, cladocerans, and mayfly nymphs (Hoxmeier and DeVries 1997; Moore and Cotner 1998). This information suggests that sturgeon and paddlefish should remain relatively active and use main channel habitat in the Ohio River during winter.

Species such as blacknose dace may move into crevices beneath rubble (Cunjak and Power 1986). Other cyprinid species may become hyporheic, burrowing into gravel at depths of 0.5 m (Emery et al. 1978). Bullheads can burrow into the substrate within backwaters presumably to take advantage of elevated thermal conditions (Loeb 1964; Bouvet et al. 1985). Overwintering tactics of many often overlooked species in the Ohio River (i.e., those with little commercial or recreational value) may be quite unique.

Summary

Winter habitat requirements of Ohio River species will revolve around the relative impacts of temperature, oxygen concentration, flow velocity, and perhaps food availability. Fish assemblages will contain species with varying tolerances to these winter conditions, affecting their habitat fidelity, condition, and survival. Because many species found in the Ohio River likely home to the same overwintering locations each year, as they do in other riverine systems (e.g., Pitlo 1987), these areas are likely very important for survival during this critical period (Sheehan et al. 1990). Winter temperatures vary in severity and duration throughout the Ohio River. Hence, constraints on overwinter success and factors influencing habitat use may vary depending on river mile. In addition, the vulnerability of fish to vessel-induced displacement during winter will depend largely on the interaction among winter conditions, habitat availability, and

habitat use. Future work exploring fish-habitat associations during winter in the Ohio River will begin to lend insight into these important issues.

Table 1-1. Predicted habitat used by fish species commonly found in the Ohio River during winter.

		Performance at < 4°C			Winter Habitat Use	
Species	Survival	Swimming Ability	Low oxygen	Activity/ Foraging	Upper River	Lower River
Largemouth Bass*	Medium	Low	Low	Low	Backwater	Backwater/ Channel
Channel Catfish*	High	Medium	Medium	Medium	Backwater/ Channel	Backwater/ Channel
Crappie*	Medium	Low	Low	Low	Backwater	Backwater/ Channel
Walleye	High	High	Low	Medium	Backwater/ Channel	Backwater/ Channel
Bluegill*	Low	Low	Low	Low	Backwater	Backwater/ Channel
White Bass*	Low	Low	N/A[a]	Low	Backwater	Backwater/ Channel
Freshwater Drum*	Low	Low	Low	Low	Backwater	Backwater/ Channel
Gizzard Shad*	Low	Low	Low	Low	Backwater	Backwater/ Channel
Carp*	High	Medium	Medium	Medium	Backwater/ Channel	Backwater/ Channel
Sturgeon/Paddlefish*	High	High	N/A[a]	High	Open Channel/ Channel	Open Channel

[a]Not Available

*Species encountered during winter 2002-2003 sampling

Chapter 2 – Smithland Pool Field Sampling 2001-2003

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Introduction

Winter is a critical period in which high mortality occurs in fishes (Oliver et al. 1979; Cunjak 1996; Garvey et al. 1998). Many temperate fishes undergo a torpor-like state when exposed to prolonged cold temperatures and short days (Crawshaw 1984) and, as such, may be highly susceptible to vessel-passage induced displacement from velocity shelters. Because the Ohio River extends through mid-temperate latitudes, inter-annual variability in winter temperature may translate to highly variable responses of fish populations to acute abiotic perturbations (see Garvey et al. 1998) such as changes in flow velocity and flow direction with navigation. Laboratory (Sheehan et al. 1990; 2000a) and field studies (Sheehan et al. 1990b; Logsdon 1993; Johnson et al. 1998) showed that a number of Mississippi River fishes overwinter in stratified backwater areas, when they have access to them, or in low velocity areas in channels. Relatively small (0.08 to 0.16 $m \cdot s^{-1}$) velocity changes, such as those that can be induced by vessels, can displace small bluegill and channel catfish from low velocity habitats when water temperatures are low (1 to 4 ^{o}C) (Sheehan et al. 2000b). If fish are displaced into flowing channels at such temperatures, mortality will probably increase (Bodensteiner and Lewis 1994; Sheehan et al. 2000a).

In this chapter, we describe research conducted in Smithland Pool, Ohio River during winters 2002 and 2003 to determine the habitat use of fish and to assess the

relative vulnerability of species and habitats to potential displacement by barge traffic. Fish were sampling with variable-depth AC electrofishing. Their relative abundance was then analyzed as a function of water quality parameters quantified at each site and sampling date.

Study Site

Smithland Pool was created by the formation of Smithland Lock and Dam in 1981. It is 115 km long and 11,134 ha at normal pool. After Smithland Lock and Dam was completed, water levels rose 5 m. Twenty six tributaries enter the pool, with the Wabash and Saline Rivers being the largest. Smithland Pool is currently the last pool of the Ohio River, with open river extending the reminder of its length to the confluence with the Mississippi River.

Methods and Approach

Habitat Assessment

During November 2001 we selected thirty sampling sites in the Smithland Pool of the Ohio River. These sites were selected to represent the five main macrohabitat types found in this section of the river (artificial, backwater, island, main channel, and tributary). Due to the scarcity of backwater habitat in the Smithland Pool, we combined backwater and island sites into one habitat category to represent the areas upstream, downstream, and on the non-channel side of islands (now called "Island"; Table 2-1). Main channel sites were typically located at areas with submerged boulders and other submerged structures that provide potential velocity shelters (Table 2-2). The sites were divided equally between the upper and lower halves of the pool and were stratified

relative to habitat type abundance in these halves (Table 2-2, Figure 2-1). During both 2002 and 2003, the abiotic characteristics of each site (specific conductance, dissolved oxygen, flow, secchi depth, and temperature) were quantified during each sampling trip with a Hydrolab Quanta water quality meter. Dissolved oxygen-temperature profiles were taken at each site. Quantities presented herein are water column averages, because neither temperatures nor dissolved oxygen concentrations varied by more than about 1% from the surface to the bottom at all sites and dates (i.e., stratification was absent). Six hobo-temp temperature-data recorders were placed in the pool near the bottom during both years. We also obtained daily discharge data during the study period from a USGS gauging station at Metropolis, Illinois.

Objective 2: Winter Fish Sampling

During 2002 and 2003, we used variable-depth, three-phase AC electrofishing (Multiquip 5000- watt generator with Honda motor) to quantify the habitat-specific relative abundance, species composition, size structure, and age structure of fishes in Smithland Pool during mid winter through late spring. The AC electrofisher consisted of three weighted electrodes that were lowered to a desired depth (usually 5-9 m). Current output typically ranged between 7-10 amps.

Sampling session 1 of the first sampling year occurred during January 2002. Session 2 of year 1 was conducted during late February through early March 2002. The third sampling session of year 1 was completed in June 2002. During the second sampling year, we sampled a small number of sites during fall 2002, although conditions deteriorated rapidly, thereby preventing us from including these data in most analyses. The first full sampling session of year 2 (i.e., henceforth session 1, 2003) was completed

during February through March 2003. The second session of year 2 was conducted in April 2003. The third session occurred during June 2003. Unavoidable factors during 2002 (elevated water levels, high flow rates, and extremely low conductivity) hindered sampling four sites during session one and two sites during session two (see Figure 2-2). Spring flooding delayed the third sampling effort during year 1 (Figure 2-2, upper panel). Similarly, during 2003, adverse conditions prevented sampling of most artificial sites during session 1 and nearly all sites during session 2 (Figure 2-2, bottom panel).

Sampling of all sites consisted of thirty minutes of non-continuous pedal time when possible. We idled backwards down-river to keep the probes at desired depths (5-9 m) beneath the boat. When possible, we distributed sampling effort at each site across two or three transects stratified across different depths. Sites that covered only a small area or contained high densities of fish were sampled during a shorter time. Fish collected were either taken back to the laboratory or measured in the field to the nearest 1 mm and released. All freshwater drum (*Aplodinotus grunniens*), channel catfish (*Ictalurus punctatus*), white bass (*Morone chrysops*), and crappie (*Pomoxis* spp.) were frozen and processed in the laboratory as per the approved scope of work. We grouped black crappie (*Pomoxis nigromaculatus*) and white crappie (*Pomoxis annularis*) into a single generic category. Because our sampling during year 1 revealed that blue catfish were abundant in Smithland Pool, we also collected individuals of this species for analysis during year 2. In the laboratory, the four target species and blue catfish were weighed (to the nearest 1 g) and measured (to the nearest 1 mm). Otoliths (and pectoral spines for catfish) were then removed for age determination. Two readers independently read all structures. For age estimates that were not in 100% agreement, readers consulted until agreement was met. If the readers could not agree, the structure was dropped from

the analysis. We also removed stomachs of a size-stratified sample of freshwater drum from the two winter sampling sessions during year 1 to determine whether foraging occurred during winter.

Results

General Patterns Both Years

Our reconnaissance of habitat in Smithland Pool suggests that low velocity, deep-water areas that may provide shelter for fish during winter are quite limited, particularly given the lack of extensive backwater habitats. Discharge was typically high during winter through late spring of both years (Figure 2-2). During both winters, we were only able to sample during three relatively short periods of low discharge and low gage height (Figure 2-2). During the remainder of both winters, water levels were typically 3-6 m above that conducive to effective, safe sampling (Figure 2-2). Only one temperature recorder was successfully retrieved from the bottom of Smithland Pool during 2002 and no loggers were retrieved during 2003. The one logger that was found revealed that temperatures declined to 4°C during a brief period in early January 2002 and then remained 5-7°C through the second sampling session (Figure 2-3, upper panel). During mid-May through June 2002, temperatures rose, exceeding 25°C by the end of sampling session 3 (Figure 2-3, upper panel).

Because all of our loggers were lost in 2003, we obtained daily water temperatures from the Shawnee Fossil Power Plant below Smithland Dam (Figure 2-3, bottom panel). These temperatures are quantified at a fixed level that is near the surface at normal flow. The logger's daily temperatures were related to that of the power plant (R^2=0.88, slope= 1.08), suggesting that the temperatures obtained from this source during

2003 reflected those occurring in the pool. However, surface temperatures were more variable than those at the bottom during winter (particularly at surface temperatures 5-15°C; Figure 2-3, bottom panel) revealing that temperatures at the bottom of Smithland Pool appeared to be more stable during this time. Daily temperatures from the power intake suggest that temperatures were likely near zero in Smithland Pool during the first sampling session of 2003. Temperatures were 11-12 °C during the second session and averaged 20 °C during the third session.

Water Quality

2002 Conditions

During sampling session 1 of 2002, mean water column temperatures ranged from 2.58 to 4.62 °C across sites (Table 2-3). Mean dissolved oxygen for the first session of this year ranged from 4.92 to 7.52 mg/L (Table 2-3). Sites during the first session had low flow rates with many (N=14) having no measurable flow (Table 2-3). Conductivity for five of the seven tributary sites sampled was lower than artificial, island, or main channel sites with values as low as 0.213 mS/cm (Table 2-3). Aside from those tributary sites, remaining conductivity values ranged between 0.500 and 0.700 mS/cm (Table 2-3). Water temperatures in session 2 of 2002 were warmer, ranging between 5.39 °C and 9.75 °C (Table 2-4; Figure 2-3). This wide range of temperatures may be attributed to varying factors (such as a longer sampling period, increased flow rates, and weather events). Dissolved oxygen during session 2 of this year ranged from 4.64 to 7.12 mg/L (Table 2-4). Flow rates during session 2 of 2002 were higher than in session 1 at 13 sites (Table 2-4; also see Figure 2-2). Twenty-two sites in session 2 had lower conductivity than during session 1 (Table 2-4). By June 2002, water temperatures were higher and dissolved

oxygen concentrations were lower in all sites relative to the other sampling dates (Table 2-5). Dissolved oxygen concentrations in tributaries were lower than in the other sites. In fact, several of the tributary sites were inaccessible due to low flow and low water depth.

To summarize conditions during winter 2002, sites could be characterized by flow, temperature, dissolved oxygen, specific conductance, and secchi depth during the coldest sampling session in January, although they did not separate by our habitat type definitions. Through the entire season, temperatures increased in all sites (Table 2-6). Mean dissolved oxygen declined more in tributaries than in other sites by spring 2002 (Table 2-6). Water clarity declined as average flow rates increased in the sites associated with the main channel (but not the tributaries) during late winter through late spring (Table 2-6). These results suggest that the tributary sites became more physically distinct (i.e, lower flow and oxygen) than those associated with the main site during late winter through spring (Table 2-6).

2003 Conditions

During the 2003 sampling session 1, temperatures were typically low (< 3°C) at all sites (Table 2-7; Figure 2-3). Higher temperatures at tributary site are due to the relative late sampling (mid March) of these sites relative to the main channel ones (mid February), a consequence of the high discharge and frequently truncated sampling effort. Dissolved oxygen concentrations during session 1 of 2003 were high at all sites (Table 2-7). Flow rates were higher at island and main channel sites, resulting in lower water clarity than in the tributary sites (Table 2-7). Specific conductance during session 1 was lower in tributaries than in sites associated with the main channel (Table 2-7). Persistent,

high discharge during sampling session 2 of 2003 made sampling difficult, and only a subset of sites were sampled. Conditions were similar among all sites during session 2, although flow was much lower (or zero) in tributaries (Table 2-8). By June through early July 2003, flow was near zero in tributaries and dissolved oxygen concentrations were low (Table 2-9). In other sites, flow rates and dissolved oxygen concentration were higher, with lower water clarity (Table 2-9).

In summary, water quality and flow patterns during our 2003 sampling were similar to those during winter 2002. Chronically high discharge rendered sampling challenging. Temperatures increased during the season, with dissolved oxygen concentrations declining more in tributaries than at other sites associated with the main channel (Table 2-10). Tributary sites during 2003 again became more distinct as the year progressed, although they typically had lower flow, higher water clarity and lower dissolved oxygen concentrations (Table 2-10).

Winter Multivariate Analysis

Because this was the coldest period during winter, we further explored abiotic characteristics of sites during 2002 and 2003 with principle components analysis (PCA), including temperature, dissolved oxygen concentration, secchi depth, flow rate, and conductivity in the analysis. The first two principle components explained 70% of the variance in the data. Principle component 1 had strong positive associations (eigenvectors > 0.4) with secchi depth and negative associations with flow and dissolved oxygen (Figure 2-4). Principle component 2 was negatively associated with temperature and dissolved oxygen and positively associated with specific conductance (Figure 2-4). Sites clustered somewhat by our defined habitat types (i.e., artificial, island, main, and

tributary; Figure 2-4). Tributary sites typically sorted out on the right side of the ordination plot, which corresponded with low dissolved oxygen, high secchi depths, and low flow (Figure 2-4). The four tributary sites in the lower right-hand quadrant of the plot are those that were sampled relatively late during winter 2003, and thus had higher temperatures than other sites (Figure 2-4). Three other clusters of sites occurred that did not appear to be closely related to out habitat delineations, although most were associated with the main channel. Typically all these sites corresponded with high conductivity and low temperatures but were probably separated primarily by flow and dissolved oxygen concentration (Figure 2-4). The two main channel sites clustered in the upper left quadrant of the plot were characterized by high flow, high dissolved oxygen, and cold temperatures (Figure 2-4). Artificial sites that created deep scour holes appeared to be intermediate in characteristics between tributaries and the main channel (Figure 2-4). These results suggest that sites do differ in abiotic characteristics during winter. If we understand species-specific requirements during winter, then these sites might be categorized for management.

Winter Fish Assemblages- Annual Patterns

Fish 2002

Samples from session 1 in January 2002 were dominated by freshwater drum (N= 333) and blue catfish (*Ictalurus furcatus*) (N= 58), accounting for > 89% of fish captured (Tables 2-11 through 2-13). Only two other species, emerald shiner (*Notropis atherinoides*) (in the island habitat type) and crappie (in the tributary habitat type), accounted for > 5% of the catch for any given habitat type (Table 2-12). Overall catch per unit effort (CPUE) was highest in artificial habitat types (60.30 fish per hour) followed

by main channel (49.50 fish/hr), tributary (44.65 fish/hr), and island (38.57 fish/hr) (Table 2-13). Tributary sites contained the most species (N=11) whereas the main sites contained only freshwater drum (Table 2-13). Artificial and island sites adjacent to the main channel contained intermediate numbers of species including channel catfish, blue catfish, and gizzard shad (Table 2-13).

Patterns for sampling session 2 during February through March 2002 were similar to those for session 1 of that year. Freshwater drum (N= 514) and blue catfish (N= 334) (Tables 2-14 through 2-16) accounted for > 97% of all fish captured during this session (Table 2-15). Island and tributary habitats contained far fewer fish (23.14 fish/hr and 36.92 fish/hr respectively) than did artificial and main channel habitats (110.53 fish/hr and 176.67 fish/hr respectively) (Table 2-16). Catch rates at the artificial and main channel sites were much higher than those at the same sites during session 1. Three sites (one tributary site from session 1 and one artificial and one island site from session 2) were excluded from these results due to extremely high catch rates (primarily consisting of freshwater drum and blue catfish). The number of species found in tributaries declined to eight during session 2 (Table 2-16). Channel catfish, blue catfish, and gizzard shad were captured in addition to freshwater drum at main sites during this time (Table 2-16). Artificial and island sites again contained intermediate numbers of species (Table 2-16), with blue catfish dominating catches in artificial sites.

By June 2002, total catch rates had declined at all sites (1.50 – 5.00 fish/hr; Tables 2-17 through 2-19). Although still dominant in the catch, freshwater drum and blue catfish only comprised about 71% of species captured (Table 2-18). Most of this decline occurred because catch rates in artificial and main sites declined (Table 2-19). Twelve species were sampled with channel catfish and gizzard shad becoming more prevalent;

only two species occurred in tributaries. Freshwater drum were absent and gizzard shad were abundant in tributary sites during this time (Table 2-19).

In summary for 2002, freshwater drum and blue catfish were the most abundant species sampled (Table 2-20). The majority of fish were associated with scour areas near artificial habitats (Table 2-20). Main channel sites produced the second highest number of fish (Table 2-20). It is important to note that this interpretation does not incorporate relative effort at each site. We will explore these issues in depth in a future section below.

Fish 2003

During February through March of 2003, freshwater drum and blue catfish dominated samples, accounting for 92% of fish captured (Tables 2-21 through 2-23). Other species that were moderately abundant in samples included goldeye, channel catfish, and smallmouth buffalo (Table 2-22). Overall catch per unit effort (CPUE) was highest in main channel sites, largely due to the high densities of freshwater drum (Table 2-23). CPUE in artificial and island habitats were equivalent, whereas tributary catch rates were quite low (Table 2-23). Artificial sites contained the most species (N=11) and tributary contained the least (N=4).

During session 2 of 2003, total number of species sampled were much lower, (Tables 2-24 through 2-26), largely due to our truncated sampling. Again, blue catfish and freshwater drum were the most abundant, primarily in artificial habitats (Table 2-26). The number of species captured was much lower (N=4 artificial, N=3 island, N=4 main, N=2 tributary).

Total catch rates were still low in June 2003, although our effort was much

greater. Blue catfish were the dominant species captured, with freshwater drum being less abundant (Tables 2-27 through 2-29). These two species again accounted for the majority (89%) of species sampled. Overall CPUE was much lower than the session 1, 2003 sample, although catch rates were still highest in main channel and artificial sites (Table 2-29). Species richness was again much lower than during the first sampling session of 2003 with a maximum of six species sampled in the artificial and main sites and only two in tributaries.

As in 2002, freshwater drum and blue catfish were the most abundant species at our sites (Table 2-30). Again, artificial sites followed by main channel ones harbored the highest number of fish (Table 2-30). The composition of species differed somewhat from 2002, but the total number of species sampled was the same between years (N= 19 each year).

General Fish Assemblage Patterns

To explore the effect of date and habitat type on habitat use by the three most common species (freshwater drum, blue catfish, and channel catfish), we combined the fish CPUE data across the two years and conducted a two way ANOVA (main effects: date and habitat). For freshwater drum, both session ($F_{2,98}$=7.48, P=0.001) and habitat ($F_{3,98}$=7.67, P=0.0001) affected CPUE, which likely occurred because overall CPUE declined through the season and CPUE was consistently higher in main channel habitats (Figure 2-5, upper panel). For blue catfish, neither habitat nor date affected CPUE (Figure 2-5, middle panel). However, it is important to note that catch of blue catfish was consistently low in tributaries (Figure 2-5). Channel catfish CPUE was only affected by habitat ($F_{3,98}$=5.12, P=0.002), which likely occurred because abundances were

consistently higher in main and island sites (Figure 2-5, lower panel).

We conducted a species assemblage PCA for each year to further explore how habitats differed among sampling dates. Only the 2002 analysis produced interpretable patterns. And in this analysis, the first and second principle components only explained 45% of the variance in the data set, suggesting that differentiating species assemblages by our site designations only weakly captured the variation in the data. Significant loadings did not occur for any of the abundant species such as freshwater drum, blue catfish, and channel catfish, perhaps because they were present in all sites during some dates. Species expected to reside in tributary sites were indeed associated with tributaries during the January and February-March 2002 sampling sessions (Figure 2-6). In January, tributaries were characterized by relatively high catches of flier, crappie, redear sunfish, and spotted bass (right upper quadrant, Figure 2-6). By session 2 of 2002, bluegill, longear, and warmouth were more closely associated with tributaries (lower left quadrant, Figure 2-6). By June, the tributary sites were more similar to the cluster of main, island, and artificial sites (upper left, Figure 2-6). This analysis suggests that tributaries had different assemblages (more lentic type species) than main channel sites during winter. This distinction declined by June 2002, perhaps as dissolved oxygen concentrations declined in the deeper waters of tributaries and most species moved into shallower water. Recall, richness of these tributary sites declined by June (Table 2-19).

To further explore relationships among species abundances, sites, and abiotic characteristics during the winter 2002 and 2003 sampling sessions, we used another ordination technique, non-metric multidimensional scaling (NMS). Only the three most abundant species (freshwater drum, blue catfish, and channel catfish) were included in the analysis. As with the PCA, no structure was found in the 2003 data set, so we only

present the results for the 2002 analysis (PC ORD, using the Sorenson distance measure). Abiotic characteristics had little influence on the data structure during winter 2002. However, we did find insightful associations between species and habitats. Blue catfish clustered with artificial sites (Figure 2-7). As our ANOVA (see above) demonstrated, freshwater drum were more closely associated with main channel habitats, whereas channel catfish appeared to cluster with island sites (Figure 2-7).

Body size may influence the habitat used by fish. Across all of the sites, no apparent pattern of size-specific habitat use arose, with the exception of freshwater drum during both 2002 and 2003 (Figure 2-8). When freshwater drum were present in the tributaries, average sizes were smaller than those of counterparts in the main channel sites. These small freshwater drum were absent from tributaries by late spring. We generally confirmed this interpretation with a two way ANOVA including data from the first two sampling sessions each year. For 2002, neither session nor habitat appeared to effect size of freshwater drum. However, in 2003, both session ($F_{1,19}$=6.89, P=0.02) and habitat ($F_{3,19}$=48.28, P=0.0001) did affect mean size of freshwater drum, with sizes being much smaller in tributaries.

By combining data for both years, we explored how species richness changed with abiotic factors in each habitat type. Because our power was low, we used an alpha of 0.1 as our cutoff for significance in our linear regressions. Species richness declined with increasing temperature at both island and tributary sites and remained unchanged in the artificial and main channel habitats (Figure 2-9). At only the island sites was species richness positively related to dissolved oxygen concentration (Figure 2-10), with no other apparent relationships occurring. Flow only appeared to affect richness in tributary sites, with the highest richness occurring when tributaries had moderate flow (Figure 2-10).

Species-Specific Patterns

The five species targeted for in-depth analysis were freshwater drum, channel catfish, black/white crappie, and white bass. During 2003 we added blue catfish. During 2002, average lengths of channel catfish were greater than those of the more abundant blue catfish (Table 2-20). Freshwater drum averaged 212 mm (Table 2-20). Average size of the six white bass caught was 277 mm (Table 2-20). During 2003, average lengths of channel catfish were again greater than those of blue catfish (Table 2-30). Average size of freshwater drum during 2003 was similar to 2002 at 239 mm (Table 2-30). Age ranges differed among species (Figure 2-12). Ages of freshwater drum spanned 28 years (Figure 2-12). Individuals of the other three species were never older than 12 years (Figure 2-12). The von Bertalanffy length at age relationship was L=708(1-exp(-0.094(t+1.06)) for freshwater drum. For channel and blue catfish, growth did not appear to decline during later years, suggesting that we did not capture the oldest individuals in the population. Supplemental sampling, perhaps using different gear types (e.g., gill nets, fyke nets), is needed to collect more channel catfish, crappie, and white bass to generate robust age and growth information.

During the two winter sampling sessions, lengths of freshwater drum ranged from 80 to 700 mm, with an average of 205 mm (Figure 2-13). By June 2002, total catch rates declined and small, young individuals < 200 mm were absent from our catch (Figure 2-13). The same pattern occurred during fall 2002 through late spring 2003 (Figure 2-14). Using analysis of covariance (ANCOVA) in which length was the covariate and sampling session was the main factor, we found that these regression lines differed among sampling sessions (ANCOVA: $P < 0.05$), with the intercept declining by June. For both years, we computed relative weight (W_r) for freshwater drum, finding that these values

ranged widely between 70 and 150% (Figures 2-15 and 2-16). Although fits were poor (R^2<0.07 for most sessions), regression revealed that W_r increased slightly with length (P<0.05, both regressions) during the first two sessions of 2002 (Figure 2-15) and during February and April of 2003 (Figure 2-16). By June of both years, condition was unrelated to length (Figure 2-15 and 2-16). Small freshwater drum had a lower proportion of empty stomachs than large counterparts during the two cold winter sessions (Figure 2-17). Of the 28 individuals that contained food, 53%, 11%, and 35% contained mayfly larvae, mollusk/gastropods, and crayfish, respectively.

Channel catfish sizes ranged from 150 – 650 mm total length during winter through late spring 2002 and 2003, with two apparent age classes dominating the distribution in 2002 and one in 2003 (Figures 2-18 and 2-19). Relative weight did not vary with length during 2002 (Figure 2-20). In 2003, relative weight only increased with length during the last sampling session, although this was the only session in which fish > 600 mm were sampled (Figure 2-21). Average condition was 102 in 2002, ranging from 80 to 130 (Figure 2-20). In 2003, average condition was 87 (Figure 2-21), lower than 2002.

In contrast to freshwater drum, blue catfish length frequency distributions did not change appreciably during the winter through spring in 2002 or 2003 (Figures 2-22 and 2-23). Because standard weight equations are not readily available for blue catfish, we conducted an ANCOVA on length-weight relationships to compare growth during each session of each year (Figures 2-24 and 2-25). During both 2002 (P=0.0001) and 2003 (P=0.0001), intercepts but not slopes differed among sessions, suggesting that average fish weights changed during the year. During both years, the intercepts declined through the year, suggesting that weight declined as the winter progressed, although the biological

relevance of this change is uncertain (Figure 2-24 and 2-25).

Discussion

Unlike the upper Mississippi River in which extensive backwater systems provide wintering habitat for fishes, our field reconnaissance of Smithland Pool revealed that this portion of the Ohio River does not contain these habitats. Rather, deep-water, low velocity, and high temperature sites in this system often required by fish during winter (see Chapter 1) may be associated with the island, artificial scours, and tributary sites. Unlike backwater habitats in other systems, our sites generally did not stratify because oxygen concentrations and temperatures were similar throughout the water column. Understanding how these sites provide shelter both from negative winter conditions as well as from potential displacement by navigation is paramount for predicting the impacts of increased navigation traffic or climate change.

Results generated during January through June 2002 and during a similar period in 2003 suggest that sites associated with the main channel (including the artificial and island areas) often differ subtly in their abiotic conditions during winter. Tributary sites fell out as distinct during winter, with low flow, high clarity, and low oxygen. Even given the subtle physical differences that emerged, most sites had relatively warm temperatures ($\geq 4^{\circ}C$), low flow rates, and moderate dissolved oxygen concentrations relative to northern rivers in which channel temperatures reach much lower temperatures and higher flow velocities during winter (Chapter 1). Still, subtle differences among sites in Smithland Pool did affect fish abundance. Species exhibited some site-specific habitat use. And, finally, we could only sample during rare periods of low discharge, although flow rates in the main channel were frequently much greater than those we quantified.

Thus, species habitat use we quantified may reflect much greater differences in flow among sites during times when we could not sample. To gain more resolution about how these sites contribute to fish habitat preference and influence susceptibility to navigation, more complete physical information through time is necessary to determine how physical characteristics vary on a daily basis.

We selected variable depth electrofishing to sample fishes in deep-water sites. In backwaters of the Mississippi River during winter, this technique was non-selective for a wide range of fish species (Sheehan et al. 1990). The total number of species sampled with this technique across sites in Smithland Pool was low relative to Sheehan et al. (1990), with freshwater drum and blue catfish occurring most frequently. To effectively determine if these two species were simply numerically dominant at these sites or if this technique is selective for them, we must compare the catch composition of variable-depth electrofishing with that generated by gill nets and trap nets at several sites A pilot study has been conducted behind chevron dikes in Pool 25 of the upper Mississippi River, where colleagues and I have compared variable depth electrofishing with Missouri trawls and purse seines during December 2002. We found species assemblages similar to those in Smithland Pool. All gears produced generally the same sizes and relative abundances of fish species.

Freshwater drum, channel catfish, and perhaps blue catfish should swim well at moderately low main channel temperatures (2-4°C; Chapter 1), potentially explaining their ubiquitous presence during the entire winter. For freshwater drum, small individuals were present in tributaries in which flow was lower. This apparent size-specific partitioning of habitat may be related to differences in tolerance to differences in flow and temperature between tributaries and the main channel (Chapter 1). It is

important to note that our measurements of flow were taken near the surface, although fish were near the bottom. Hence, our estimates of flow may not accurately reflect the flows experienced by the fish. Future work will involve using an acoustic doppler current profiler recently acquired by the Fisheries and Illinois Aquaculture Center at SIUC to explore how flow varies at these bottom sites. We also must determine how flow changes throughout the water column during and after vessels have passed in proximity to these potential overwintering sites (see Executive Summary, Figure 1 for some preliminary findings).

We would expect greater use of the artificial scour areas in the main channel if these sites were used for refuge. Blue catfish appeared to have some association with these sites, although other species were infrequent. Although we might expect main channel areas to be exposed to displacement from barges or high flow, freshwater drum use of these sites was high during both years and only declined by late June, suggesting that these sites are preferred during cold months, perhaps due to enhanced foraging opportunities. Channel catfish use of the main channel and island sites was consistently high during both years. Why these species showed different apparent preferences for these habitats can only draw speculation, but this pattern was consistent between years and likely is related to the species-specific interactions between flow, temperature, and perhaps food availability. Overall abundance of fish declined with increasing temperature. This may be expected if many species using deep-water habitat during winter dispersed to different depths as temperatures increased.

Quantifying the number of species encountered at a site (i.e., richness) is another approach for estimating use. Physical factors at sites did appear to affect general use by species, with tributary and island backwater sites showing the most change. Species

richness increased in both island backwater and tributary sites with declining temperatures, suggesting that these areas might provide a refuge for species as temperatures decline. Flow rates at both of these sites were consistently lower than those in the main channel, supporting this view. Interestingly, species richness increased in tributaries with a slight increase in flow in these areas. These flow rates were still much lower than those in the main channel. Thus, the increase in species use with increased tributary flow may be related to an increase in connectivity of these areas with the main channel. Although we would expect fish species use in tributaries to be strongly tied to the low dissolved oxygen concentrations that often occurred at these sites, this did not occur. Fish species richness was only consistently low in tributaries when dissolved oxygen concentrations were less than 5 mg/L.

Body condition (i.e., relative weight) of freshwater drum was positively related with size and did not change during the winter sessions of 2002 and 2003. However, condition did decline by late spring, perhaps because individuals had expended energy for spawning. Other species such as channel catfish, white bass, and crappie had high relative weights during the study period. Relative weight often corresponds well with fat content in fishes. If this holds true for these populations, then these fish were likely consuming sufficient food to offset energetic costs of overwintering. Foraging did occur in freshwater drum, although it was size dependent. Smaller individuals foraged more frequently than large counterparts, perhaps because these individuals (which had lower condition values) required more energy intake to offset higher mass-specific metabolic rates and lower fat reserves.

Size distributions did change during winter in consistent ways during the two sampling years. Small freshwater drum were predominant in distributions during the

winter but declined by the late spring/summer sampling. Distributions of blue catfish, the other species for which we have sufficiently abundant size data, changed little during the sampling sessions. Potentially, small freshwater drum are moving from deep water and tributary habitats to forage in other habitats as temperatures increase. A contrasting interpretation would be that small individuals suffered higher mortality by late spring. However, condition of all individuals was high and thus does not support size-dependent winter mortality. All sizes of blue catfish appear to remain at sites that we sampled during winter through late spring/early summer.

Summary

Relative to late spring, fishes were more abundant in relatively rare, tributary or deep-water scour areas adjacent to the main channel when temperatures were < 10°C (expectations are outlined in Chapter 1). Fish assemblages in tributaries did differ from the main channel sites during winter, primarily because species that typically occupy more lentic systems were only present in tributaries (particularly in 2002). High catch rates at deep-water artificial sites and in the main channel during winter suggest that these sites are quite important for some species, including the commercially important blue catfish. During cold months, fish using sites adjacent to or directly in the main channel with low velocity refuges may be subject to displacement by barge traffic. As such, we would expect that survival of species that use these areas will be compromised by navigation. Both winter through spring 2002 and 2003 were characterized by high flow and relatively mild temperatures. Future research must explore how site-specific flow rates, temperatures, and fish use of these areas change as a function of different winter conditions (e.g., a more severe, dry winter) and proximity to navigation traffic (see

Executive Summary).

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Table 2-1. Sites selected for sampling during winter through late spring 2002 in the Smithland Pool of the Ohio River.

Habitat Type	Description
Main Channel	Area extending from shore including the center of the channel.
Island/Backwater	Area between an island and the shore. May be closed at one end of the channel (i.e., creating a flow break).
Artificial Flow Break	Artificial structures such as wing dams and moorings that create relatively deep scour holes; includes lock and dam complexes
Tributaries	Streams that flow into the main channel.

Table 2-2. Sampling sites in the Smithland Pool of the Ohio River during winter through late spring 2002 and 2003.

Habitat Type	Site (#)	Location in Pool	Site Description	Mean Depth (m)	River Mile	Location N	Location W
Artificial	14	Upper	Scour adjacent to J. T. Meyers Lock and Dam	7.6	846	37.47373	87.59593
	15	Upper	Scour behind submerged wingdam on the non-channel side of Wabash Island	7.6	850	37.46600	88.00766
	43	Upper	Scour behind submerged wingdam	7.6	875	37.47103	88.10740
	54	Upper	Scour behind submerged wingdam	9.1	883	37.45419	88.19456
	2	Lower	Scour downstream from an abandoned boat ramp	7.6	902.7	37.36623	88.48194
	61	Lower	Scour behind submerged wingdam	7.6	904.5	37.33731	88.48140
	62	Lower	Scour behind submerged wingdam on the non-channel side of Pryor Island	9.1	905.5	37.32228	88.48333
	66	Lower	Scour behind submerged wingdam	10.7	906.3	37.31522	88.49349
	63	Lower	Scour behind submerged wingdam	10.7	907	37.30203	88.50331
	64	Lower	Scour behind submerged wingdam	9.1	907.3	37.29828	88.50535
	65	Lower	Scour behind submerged wingdam	10.7	907.5	37.29581	88.50651
Island	13	Upper	Non-channel side of the first island upstream of Shawneetown Bar	6.1	855	37.43134	88.05804
	20	Upper	Non-channel side of Cincinnati Island	6.1	860	37.39384	88.09156
	53	Upper	Non-channel side of Cave In Rock Island	6.1	880.5	37.46170	88.15633
	30	Upper	Between Hurricane Island and unnamed island immediately downstream	4.6	889.5	37.43806	88.30481
	25	Lower	Non-channel side of Rondeau Island	6.1	901	37.37595	88.46862
	23	Lower	Non-channel side of Pryor Island	6.1	905	37.31287	88.49214

	11	Lower	Non-channel side of the first Sisters Islands	7.6	909	37.27226	88.50574
Main	70	Upper	Numerous submerged boulders near main channel immediately	7.6	869	37.55687	88.10599
	42	Upper	Scour downstream of a sand bar	7.6	878	37.48793	88.07469
	40	Upper	Sheer rock wall exposed to main channel	9.1	880	37.46892	88.14976
	27	Lower	Numerous submerged boulders near main channel	6.1	894.3	37.40544	88.37815
Tributary	22	Upper	Saline River	7.6	867	37.57049	88.12529
	34	Upper	Big Creek	6.1	889.5	37.44280	88.31506
	29	Lower	Deer Creek	4.6	893	37.39818	88.35518
	28	Lower	Small unnamed tributary	3	893.7	37.39668	88.36796
	35	Lower	Threemile Creek	3.1	896	37.42156	88.39661
	37	Lower	Grand Pierre Creek	6.1	897.6	37.42150	88.42973
	1	Lower	Lusk Creek	6.1	902.5	37.37155	88.48615

Table 2-3. Water quality data for each site of the Smithland Pool of the Ohio River during session 1 (January 2002).

Habitat Type	Site (#)	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
Artificial	14	3.87	6.98	53	0	0.526
	15	3.81	7.12	51	*	0.526
	43	*	*	*	*	*
	54	4.36	6.84	77	0.18	0.594
	2	4.32	7.15	79	0.1	0.545
	61	4.23	7.07	69	0.2	0.592
	62	3.98	7.08	65	0	0.574
	66	4.14	7.15	73	0.2	0.59
	63	3.8	7.28	67	0	0.574
	64	3.79	7.26	66	0	0.575
	65	3.79	7.22	67	0	0.575
Island	13	2.58	7.5	39	0.05	0.646
	20	4.29	7.41	46	0.2	0.532
	53	4.49	6.91	63	0	0.587
	30	*	*	*	*	*
	25	4.32	7.12	65	0.2	0.592
	28	3.51	6.4	98	0	0.376
	11	3.7	7.28	64	0	0.573
Main	70	4.62	7.49	60	0.18	0.611
	42	*	*	*	*	*
	40	4.35	7.01	80	0.2	0.629
	27	*	*	*	*	*
Tributary	22	4.53	7.52	63	0	0.651
	34	2.8	5.85	157	0	0.373
	29	3.6	5.7	104	0	0.363
	23	4.19	7.38	59	0.25	0.56
	35	3.48	5.32	83	0	0.378
	37	3.68	5.34	123	0	0.266
	1	3.8	4.92	131	0	0.213

* Not available due to site inaccessibility or equipment failure.

Table 2-4. Water quality data for each site of the Smithland Pool of the Ohio River during session 2 (February through March 2002).

Habitat Type	Site (#)	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
Artificial	14	7.72	6.12	45	0.08	0.436
	15	7.59	6.05	46	*	0.435
	43	8.94	5.69	16	0.22	0.498
	54	5.78	6.99	50	0.2	0.492
	2	6.64	6.73	34	0.02	0.499
	61	7.73	6.11	19	0.3	0.488
	62	6.51	6.76	34	0.1	0.446
	66	7.54	6.1	19	0.6	0.5
	63	7.51	6.18	21	0.2	0.5
	64	6.84	6.68	38	0.02	0.458
	65	6.52	6.49	41	0.02	0.458
Island	13	8.81	5.41	14	0.14	0.476
	20	7.47	6.36	31	0.1	0.441
	53	6.12	7.11	41	0.05	0.482
	30	7.82	6.68	48	1.1	0.514
	25	7.64	6.38	18	0.1	0.48
	23	*	*	*	*	*
	11	6.62	6.83	28	0.2	0.45
Main	70	9.75	5.12	18	0.22	0.552
	42	8.85	5.62	16	0.02	0.498
	40	5.39	7.12	32	0.2	0.568
	27	7.51	7.06	35	0.6	0.516
Tributary	22	7.76	5.51	23	0.04	0.654
	34	7.97	5.45	31	0	0.344
	29	8.77	4.64	35	0	0.253
	28	8.62	5.96	33	0	0.31
	35	8.61	5.01	19	0	0.291
	37	7.24	6.23	34	0	0.233
	1	*	*	*	*	*

* Not available due to site inaccessibility or equipment failure.

Table 2-5. Water quality data for each site of the Smithland Pool of the Ohio River during session 3 (June 2002).

Habitat Type	Site (#)	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
Artificial	14	23.91	6.71	32	*	0.366
	15	23.7	7.2	28	*	0.362
	43	27.52	*	21	0.03	0.524
	54	22.97	6.52	31	0.08	0.372
	2	24.06	6.15	45	0.02	0.414
	61	24.85	6.16	27	*	0.415
	62	23.86	6.11	42	0.12	0.407
	66	25.07	6.1	47	*	0.417
	63	26.9	4.4	56	0	0.456
	64	23.87	6.14	45	0.06	0.406
	65	23.78	6.34	45	0.38	0.406
Island	13	24.5	7.47	15	*	0.511
	20	29.3	7.85	47	0	0.443
	53	23.18	6.92	31	0.1	0.367
	30	27.46	*	28	0.04	0.484
	25	27.64	*	59	0	0.465
	23	25.03	6.21	41	*	0.417
	11	23.69	6.22	41	0.08	0.405
Main	70	27.91	*	57	*	0.519
	42	29.8	8.99	49	*	0.526
	40	24.2	5.14	15	0.2	0.47
	27	24.7	6.3	40	*	0.41
Tributary	22	*	*	*	*	1.375
	34	22.71	*	42	0	0.369
	29	23.55	1	41	0	0.311
	28	22.96	3.1	46	*	0.28
	35	*	*	*	*	*
	37	24.29	5.67	31	0	0.424
	1	*	*	*	*	0.26

* Not available due to site inaccessibility or equipment failure.

Table 2-6. Mean water quality values across sites during three sampling sessions in Smithland Pool of the Ohio River during winter through late spring 2002.

Sampling Session	Habitat Type	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
January	Artificial	4.01	7.12	66.70	0.08	0.57
	Island	3.82	7.10	62.50	0.08	0.55
	Main	4.02	6.18	101.50	0.10	0.45
	Tributary	3.86	6.31	93.86	0.06	0.45
February-March	Artificial	7.25	6.36	31.75	0.17	0.47
	Island	7.37	6.48	32.40	0.32	0.47
	Main	7.88	6.23	25.25	0.26	0.53
	Tributary	8.16	5.47	29.17	0.01	0.35
June	Artificial	24.84	6.18	39.83	0.10	0.42
	Island	25.63	7.12	32.40	0.07	0.44
	Main	26.65	6.81	40.25	0.20	0.48
	Tributary	23.71	4.00	40.20	0.00	0.36

Table 2-7. Water quality data for each site of the Smithland Pool of the Ohio River during session 1 (February 2003).

Habitat Type	Site (#)	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
Artificial	14	2.73	13.36	28	0	0.409
	15	*	*	*	*	*
	43	2.69	13.13	29	0.02	0.562
	54	2.65	13	29	0.22	0.459
	2	*	*	*	*	*
	61	*	*	*	*	*
	62	*	*	*	*	*
	66	*	*	*	*	*
	63	*	*	*	*	*
	64	*	*	*	*	*
	65	*	*	*	*	*
Island	13	3.24	14.49	32	0	0.559
	20	2.69	13.18	27	0.2	0.453
	53	2.34	12.99	28	0.1	0.472
	30	2.81	13.39	34	0.08	0.468
	25	2.87	12.73	40	0.12	0.482
	11	3.3	12.4	43	0.1	0.471
Main	70	2.82	12.6	30	0.4	0.577
	42	2.95	13.04	24	*	0.559
	40	2.75	12.78	30	0.5	0.553
	27	2.79	12.75	40	0.2	0.459
Tributary	22	*	*	*	*	*
	34	8.18	9.14	53	0	0.327
	29	7.71	11.06	46	0	0.287
	23	*	*	*	*	*
	28	7.5	11.14	28	0	0.279
	35	*	*	*	*	*
	37	8.17	9.96	67	0	0.32
	1	*	*	*	*	*

* Not available due to site inaccessibility or equipment failure.

Table 2-8 Water quality data for each site of the Smithland Pool of the Ohio River during session 2 (April 2003).

Habitat Type	Site (#)	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
Artificial	14	12.43	7.89	30	0	0.291
	15	*	*	*	*	*
	43	*	*	*	*	*
	54	*	*	*	*	*
	2	*	*	*	*	*
	61	*	*	*	*	*
	62	*	*	*	*	*
	66	*	*	*	*	*
	63	*	*	*	*	*
	64	*	*	*	*	*
	65	*	*	*	*	*
Island	13	13.67	8.53	28	0.1	0.347
	20	13.12	8.33	29	0.08	0.303
	53	*	*	*	*	*
	30	*	*	*	*	*
	25	*	*	*	*	*
	23	*	*	*	*	*
	11	*	*	*	*	*
Main	70	13.51	8.67	28	0.28	0.351
	42	*	*	*	*	*
	40	*	*	*	*	*
	27	*	*	*	*	*
Tributary	22	*	*	*	*	*
	34	11.1	7.13	76	0	0.282
	29	11.76	6.61	61	0	0.251
	28	12.58	6.12	64	0	0.32
	35	*	*	*	*	*
	37	12.08	7.67	55	0	0.267
	1	*	*	*	*	*

* Not available due to site inaccessibility or equipment failure.

Table 2-9. Water quality data for each site of the Smithland Pool of the Ohio River during session 3 (June 2003).

Habitat Type	Site (#)	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
Artificial	14	18.52	8	28	0.8	0.303
	15	*	*	*	*	*
	43	18.43	7.5	29	0.2	0.432
	54	18.36	7.11	26	0.18	0.312
	2	28.09	7.48	38	0.2	0.336
	61	18.53	5.72	30	0.1	0.334
	62	18.74	5.56	29	0.08	0.334
	66	28.05	8.11	36	0.08	0.324
	63	19.02	5.57	29	0.08	0.336
	64	27.86	8.56	36	0.1	0.327
	65	27.81	7.89	36	0.1	0.33
Island	13	18.97	5.76	26	0.12	0.463
	20	18.86	5.88	25	0.02	0.318
	53	18.34	6.95	28	0.4	0.312
	30	18.44	7.03	24	0.1	0.351
	25	18.48	5.61	33	0.14	0.343
	23	27.8	7.5	36	0.1	0.325
	11	27.77	7.61	32	0.02	0.331
Main	70	18.97	5.9	26	0.1	0.426
	42	29.8	8.99	49	*	0.526
	40	18.49	7.5	28	0.16	0.431
	27	18.4	6.24	35	0.2	0.349
Tributary	22	*	*	*	*	*
	34	17.65	1.83	56	0	0.181
	29	18.6	1.9	96	0	0.155
	28	18.42	2.16	110	0	0.125
	35	*	*	*	*	*
	37	17.15	2.87	72	0	0.126
	1	*	*	*	*	0.26

* Not available due to site inaccessibility or equipment failure.

Table 2-10. Mean water quality values across sites during three sampling sessions in Smithland Pool of the Ohio River during winter through late spring 2003.

Sampling Session	Habitat Type	Temperature (C)	Dissolved oxygen (mg/l)	Secchi (cm)	Flow Rate (m/s)	Conductivity (mS/cm)
February	Artificial	2.69	13.16	28.67	0.08	0.48
	Island	2.88	13.20	34.00	0.10	0.48
	Main	2.83	12.79	31.00	0.37	0.54
	Tributary	7.89	10.33	48.50	0.00	0.30
March-April	Artificial	12.43	7.89	30.00	0.00	0.29
	Island	13.40	8.43	28.50	0.09	0.33
	Main	13.51	8.67	28.00	0.28	0.35
	Tributary	11.88	6.88	64.00	0.00	0.28
June	Artificial	22.34	7.15	31.70	0.19	0.28
	Island	21.24	6.62	29.14	0.13	0.34
	Main	18.56	6.64	29.50	0.17	0.35
	Tributary	17.96	2.19	83.50	0.00	0.41

Table 2-11. Total number of fish caught at each habitat type in the Smithland Pool of the Ohio River during session 1 of 2001-2002 (January 2002).

	Habitat types				
Species	Artificial	Island	Main	Tributary *	Total *
Bigmouth Buffalo	0	1	0	1	2
Blue Catfish	50	8	0	0	58
Bluegill	1	0	0	2	3
Channel Catfish	0	4	0	2	6
Common Carp	0	1	0	1	2
Emerald Shiner	0	10	0	0	10
Flathead Catfish	0	1	0	0	1
Flier	0	0	0	1	1
Freshwater Drum	142	65	33	93	333
Gizzard Shad	5	0	0	2	7
Longear Sunfish	0	0	0	0	0
Black/White Crappie	1	0	0	6	7
Quillback	0	0	0	0	0
Redear Sunfish	0	0	0	1	1
Smallmouth Buffalo	1	0	0	0	1
Spotted Bass	0	0	0	1	1
Warmouth	0	0	0	0	0
White Bass	1	0	0	2	3
Total *	201	90	33	112	436

* Excludes one tributary site with high catch of freshwater drum and catfish.

Table 2-12. Percent species composition at each habitat type in the Smithland Pool of the Ohio River during session 1 of 2001-2002 (January 2002).

	Habitat types				
Species	Artificial	Island	Main	Tributary *	Total *
Bigmouth Buffalo	0.0	1.1	0.0	0.9	0.5
Blue Catfish	24.9	8.9	0.0	0.0	13.3
Bluegill	0.5	0.0	0.0	1.8	0.7
Channel Catfish	0.0	4.4	0.0	1.8	1.4
Common Carp	0.0	1.1	0.0	0.9	0.5
Emerald Shiner	0.0	11.1	0.0	0.0	2.3
Flathead Catfish	0.0	1.1	0.0	0.0	0.2
Flier	0.0	0.0	0.0	0.9	0.2
Freshwater Drum	70.6	72.2	100.0	83.0	76.4
Gizzard Shad	2.5	0.0	0.0	1.8	1.6
Longear Sunfish	0.0	0.0	0.0	0.0	0.0
Black/White Crappie	0.5	0.0	0.0	5.4	1.6
Quillback	0.0	0.0	0.0	0.0	0.0
Redear Sunfish	0.0	0.0	0.0	0.9	0.2
Smallmouth Buffalo	0.5	0.0	0.0	0.0	0.2
Spotted Bass	0.0	0.0	0.0	0.9	0.2
Warmouth	0.0	0.0	0.0	0.0	0.0
White Bass	0.5	0.0	0.0	1.8	0.7

* Excludes one tributary site with high catch of freshwater drum and catfish (N > 500).

Table 2-13. Mean number of fish caught per hour of electrofishing among sites of the Smithland Pool during session 1 of 2001-2002 (January 2002).

	Habitat types			
Species	Artificial	Island	Main	Tributary *
Bigmouth Buffalo	0.00	0.43	0.00	0.40
Blue Catfish	15.00	3.43	0.00	0.00
Bluegill	0.30	0.00	0.00	0.80
Channel Catfish	0.00	1.71	0.00	0.80
Common Carp	0.00	0.43	0.00	0.40
Emerald Shiner	0.00	4.29	0.00	0.00
Flathead Catfish	0.00	0.43	0.00	0.00
Flier	0.00	0.00	0.00	0.40
Freshwater Drum	42.60	27.86	49.50	37.08
Gizzard Shad	1.50	0.00	0.00	0.80
Longear Sunfish	0.00	0.00	0.00	0.00
Black/White Crappie	0.30	0.00	0.00	2.39
Quillback	0.00	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.40
Smallmouth Buffalo	0.30	0.00	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.40
Warmouth	0.00	0.00	0.00	0.00
White Bass	0.30	0.00	0.00	0.80
Total	60.30	38.57	49.50	44.65
Total Effort (hours)	3.33	2.33	0.67	2.51

* Excludes one tributary site with high catch of freshwater drum and catfish (N > 500).

Table 2-14. Total number of fish caught at each habitat type in the Smithland Pool of the Ohio River during session 2 of 2001-2002 (February through March 2002).

	Habitat types				
Species	Artificial *	Island *	Main	Tributary	Total *
Bigmouth Buffalo	0	0	0	0	0
Blue Catfish	298	11	21	4	334
Bluegill	0	0	0	10	10
Channel Catfish	8	14	6	0	28
Common Carp	1	0	0	1	2
Emerald Shiner	0	0	0	0	0
Flathead Catfish	0	0	0	0	0
Flier	0	0	0	0	0
Freshwater Drum	205	28	237	44	514
Gizzard Shad	10	0	1	6	17
Longear Sunfish	0	0	0	4	4
Black/White Crappie	2	0	0	2	4
Quillback	1	0	0	0	1
Redear Sunfish	0	0	0	0	0
Smallmouth Buffalo	0	1	0	0	1
Spotted Bass	0	0	0	0	0
Warmouth	0	0	0	1	1
White Bass	0	0	0	0	0
Total *	525	54	265	72	916

*Excludes one artificial and one island site due to high catch of freshwater drum and catfish (N > 500).

Table 2-15. Percent species composition at each habitat type in the Smithland Pool of the Ohio River during session 2 of 2001-2002 (February through March 2002).

	Habitat types				
Species	Artificial *	Island *	Main	Tributary	Total *
Bigmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Blue Catfish	56.76	20.37	7.92	5.56	36.46
Bluegill	0.00	0.00	0.00	13.89	1.09
Channel Catfish	1.52	25.93	2.26	0.00	3.06
Common Carp	0.19	0.00	0.00	1.39	0.22
Emerald Shiner	0.00	0.00	0.00	0.00	0.00
Flathead Catfish	0.00	0.00	0.00	0.00	0.00
Flier	0.00	0.00	0.00	0.00	0.00
Freshwater Drum	39.05	51.85	89.43	61.11	56.11
Gizzard Shad	1.90	0.00	0.38	8.33	1.86
Longear Sunfish	0.00	0.00	0.00	5.56	0.44
Black/White Crappie	0.38	0.00	0.00	2.78	0.44
Quillback	0.19	0.00	0.00	0.00	0.11
Redear Sunfish	0.00	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	1.85	0.00	0.00	0.11
Spotted Bass	0.00	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	1.39	0.11
White Bass	0.00	0.00	0.00	0.00	0.00

*Excludes one artificial and one island site due to high catch of freshwater drum and catfish (N > 500).

Table 2-16. Mean number of fish caught per hour of electrofishing among sites of the Smithland Pool during session 2 of 2001-2002 (February through March 2002).

	Habitat types			
Species	Artificial *	Island *	Main	Tributary
Bigmouth Buffalo	0.00	0.00	0.00	0.00
Blue Catfish	62.74	4.71	14.00	2.05
Bluegill	0.00	0.00	0.00	5.13
Channel Catfish	1.68	6.00	4.00	0.00
Common Carp	0.21	0.00	0.00	0.51
Emerald Shiner	0.00	0.00	0.00	0.00
Flathead Catfish	0.00	0.00	0.00	0.00
Flier	0.00	0.00	0.00	0.00
Freshwater Drum	43.16	12.00	158.00	22.56
Gizzard Shad	2.11	0.00	0.67	3.08
Longear Sunfish	0.00	0.00	0.00	2.05
Black/White Crappie	0.42	0.00	0.00	1.03
Quillback	0.21	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.43	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.51
White Bass	0.00	0.00	0.00	0.00
Total	110.53	23.14	176.67	36.92
EF Effort (hrs)	4.75	2.33	1.50	1.95

*Excludes one artificial and one island site due to high catch of freshwater drum and catfish (N > 500).

Table 2-17. Total number of fish caught at each habitat type in the Smithland Pool of the Ohio River during session 3 of 2001-2002 (June 2002).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0	0	0	0	0
Blue Catfish	86	28	5	0	119
Bluegill	0	0	0	2	2
Channel Catfish	4	5	17	0	26
Common Carp	2	0	2	0	4
Emerald Shiner	0	0	0	0	0
Flathead Catfish	3	2	5	0	10
Flier	0	0	0	0	0
Freshwater Drum	22	14	32	0	68
Gizzard Shad	4	0	0	19	23
Longear Sunfish	1	0	0	0	1
Black/White Crappie	0	0	0	0	0
Quillback	1	0	0	0	1
Paddlefish	3	0	0	0	3
Redear Sunfish	0	0	0	0	0
Smallmouth Buffalo	0	0	2	0	2
Spotted Bass	0	0	0	0	0
Warmouth	0	0	0	0	0
White Bass	2	0	1	0	3
TOTAL	128	49	64	21	262

Table 2-18. Percent species composition at each habitat type in the Smithland Pool of the Ohio River during session 3 of 2001-2002 (June 2002).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Blue Catfish	67.19	57.14	7.81	0.00	45.42
Bluegill	0.00	0.00	0.00	9.52	0.76
Channel Catfish	3.13	10.20	26.56	0.00	9.92
Common Carp	1.56	0.00	3.13	0.00	1.53
Emerald Shiner	0.00	0.00	0.00	0.00	0.00
Flathead Catfish	2.34	4.08	7.81	0.00	3.82
Flier	0.00	0.00	0.00	0.00	0.00
Freshwater Drum	17.19	28.57	50.00	0.00	25.95
Gizzard Shad	3.13	0.00	0.00	90.48	8.78
Longear Sunfish	0.78	0.00	0.00	0.00	0.38
Black/White Crappie	0.00	0.00	0.00	0.00	0.00
Quillback	0.78	0.00	0.00	0.00	0.38
Paddlefish	2.34	0.00	0.00	0.00	1.15
Redear Sunfish	0.00	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.00	3.13	0.00	0.76
Spotted Bass	0.00	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.00	0.00
White Bass	1.56	0.00	1.56	0.00	1.15

Table 2-19. Mean number of fish caught per hour of electrofishing among sites of the Smithland Pool during session 3 of 2001-2002 (June 2002).

	Habitat types			
Species	Artificial	Island	Main	Tributary
Bigmouth Buffalo	0.00	0.00	0.00	0.00
Blue Catfish	17.20	10.50	2.50	0.00
Bluegill	0.00	0.00	0.00	1.60
Channel Catfish	0.80	1.88	8.50	0.00
Common Carp	0.40	0.00	1.00	0.00
Emerald Shiner	0.00	0.00	0.00	0.00
Flathead Catfish	0.60	0.75	2.50	0.00
Flier	0.00	0.00	0.00	0.00
Freshwater Drum	4.40	5.25	16.00	0.00
Gizzard Shad	0.80	0.00	0.00	15.20
Longear Sunfish	0.20	0.00	0.00	0.00
Black/White Crappie	0.00	0.00	0.00	0.00
Quillback	0.20	0.00	0.00	0.00
Paddlefish	0.60	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.00	1.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.00
White Bass	0.40	0.00	0.50	0.00
Total	25.60	18.38	32.00	16.80
EF Effort (hrs)	5.00	2.70	2.00	1.50

Table 2-20. Total combined catch and mean total length (mm) as a function of habitat type in Smithland Pool of the Ohio River during winter through late spring 2002.

	Number in Habitat						
Species	Artificial *	Island *	Main	Tributary *	Total *	Mean TL	SD
Bigmouth Buffalo	0	1	0	1	2	**	**
Blue Catfish	434	47	26	4	511	232.56	126.15
Bluegill	1	0	0	14	15	112.38	43.48
Channel Catfish	12	23	23	2	60	370.72	134.50
Common Carp	3	1	2	2	8	662.00	112.00
Emerald Shiner	0	10	0	0	10	**	**
Flathead Catfish	3	3	5	0	11	474.10	257.10
Flier	0	0	0	1	1	**	**
Freshwater Drum	369	107	302	137	915	212.90	123.36
Gizzard Shad	19	0	1	27	47	226.98	32.43
Longear Sunfish	1	0	0	4	5	136.60	17.85
Black/White Crappie	3	0	0	8	11	216.27	57.79
Quillback	2	0	0	8	10	442.00	80.61
Paddlefish	3	0	0	0	3	711.67	314.26
Redear Sunfish	0	0	0	1	1	**	**
Smallmouth Buffalo	1	1	2	0	4	420.25	143.86
Spotted Bass	0	0	0	1	1	**	**
Warmouth	0	0	0	1	1	131.00	
White Bass	3	0	1	2	6	276.67	113.98
Total	854	193	362	213	1622		

*Excludes sites with high catches of freshwater drum and catfish (N > 500).

**Not available.

Table 2-21. Total number of fish caught at each habitat type in the Smithland Pool of the Ohio River during session 1 of 2002-2003 (February 2003).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0	0	0	0	0
Blue Catfish	61	168	107	3	339
Bighead Carp	0	0	0	0	0
Bluegill	0	0	0	0	0
Channel Catfish	1	9	9	1	20
Common Carp	1	0	0	0	1
Emerald Shiner	0	0	0	0	0
Flathead Catfish	0	0	0	0	0
Flier	0	0	0	0	0
Freshwater Drum	142	131	294	33	600
Gizzard Shad	0	3	0	0	3
Goldeye	0	0	0	19	19
Longear Sunfish	0	1	0	0	1
Mooneye	0	2	2	0	4
Paddlefish	0	0	0	0	0
Black/White Crappie	0	0	0	0	0
Quillback	3	1	0	0	4
Redear Sunfish	0	0	0	0	0
River Carpsucker	5	0	0	0	5
Sauger	1	0	0	0	1
Smallmouth Buffalo	11	0	0	0	22
Spotted Bass	0	0	0	0	0
Shortnose Gar	0	1	0	0	1
Striped Bass	2	1	1	0	4
Warmouth	0	0	0	0	0
White Bass	1	0	0	0	1
Total	228	317	413	56	1025

Table 2-22. Percent species composition at each habitat type in the Smithland Pool of the Ohio River during session 1 of 2002-2003 (February 2003).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Blue Catfish	26.80	53.00	25.90	5.40	33.07
Bighead Carp	0.00	0.00	0.00	0.00	0.00
Bluegill	0.00	0.00	0.00	0.00	0.00
Channel Catfish	0.40	2.80	2.20	1.80	1.95
Common Carp	0.40	0.00	0.00	0.00	0.10
Emerald Shiner	0.00	0.00	0.00	0.00	0.00
Flathead Catfish	0.00	0.00	0.00	0.00	0.00
Flier	0.00	0.00	0.00	0.00	0.00
Freshwater Drum	62.30	41.30	71.20	58.90	58.54
Gizzard Shad	0.00	0.90	0.00	0.00	0.29
Goldeye	0.00	0.00	0.00	33.90	1.85
Longear Sunfish	0.00	0.30	0.00	0.00	0.10
Mooneye	0.00	0.60	0.50	0.00	0.39
Paddlefish	0.00	0.00	0.00	0.00	0.00
Black/White Crappie	0.00	0.00	0.00	0.00	0.00
Quillback	1.30	0.30	0.00	0.00	0.39
Redear Sunfish	0.00	0.00	0.00	0.00	0.00
River Carpsucker	2.20	0.00	0.00	0.00	0.49
Sauger	0.40	0.00	0.00	0.00	0.10
Smallmouth Buffalo	4.80	0.00	0.00	0.00	2.15
Spotted Bass	0.00	0.00	0.00	0.00	0.00
Shortnose Gar	0.00	0.30	0.00	0.00	0.10
Striped Bass	0.90	0.30	0.20	0.00	0.39
Warmouth	0.00	0.00	0.00	0.00	0.00
White Bass	0.40	0.00	0.00	0.00	0.10

Table 2-23. Mean number of fish caught per hour of electrofishing among sites of the Smithland Pool during session 1 of 2002-2003 (February 2003).

	Habitat types			
Species	Artificial	Island	Main	Tributary
Bigmouth Buffalo	0.00	0.00	0.00	0.00
Blue Catfish	53.74	126.00	89.20	7.20
Bighead Carp	0.00	0.00	0.00	0.00
Bluegill	0.00	0.00	0.00	0.00
Channel Catfish	3.53	9.00	18.00	2.40
Common Carp	2.40	0.00	0.00	0.00
Emerald Shiner	0.00	0.00	0.00	0.00
Flathead Catfish	0.00	0.00	0.00	0.00
Flier	0.00	0.00	0.00	0.00
Freshwater Drum	153.91	98.25	249.20	23.73
Gizzard Shad	0.00	9.00	0.00	0.00
Goldeye	0.00	0.00	0.00	12.98
Longear Sunfish	0.00	3.00	0.00	0.00
Mooneye	0.00	3.00	8.00	0.00
Paddlefish	0.00	0.00	0.00	0.00
Black/White Crappie	0.00	0.00	0.00	0.00
Quillback	10.59	3.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00
River Carpsucker	17.65	0.00	0.00	0.00
Sauger	3.53	0.00	0.00	0.00
Smallmouth Buffalo	38.82	0.00	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00
Shortnose Gar	0.00	3.00	0.00	0.00
Striped Bass	7.06	3.00	2.40	0.00
Warmouth	0.00	0.00	0.00	0.00
White Bass	3.53	0.00	0.00	0.00
Totals	59.17	52.83	116.67	13.03

Table 2-24. Total number of fish caught at each habitat type in the Smithland Pool of the Ohio River during session 2 of 2002-2003 (April 2003).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0	0	0	0	0
Blue Catfish	20	1	1	0	22
Bighead Carp	0	0	0	0	0
Bluegill	0	0	0	0	0
Channel Catfish	1	1	1	1	4
Common Carp	0	0	0	0	0
Emerald Shiner	0	0	0	0	0
Flathead Catfish	1	0	1	0	2
Flier	0	0	0	0	0
Freshwater Drum	12	1	3	2	18
Gizzard Shad	0	0	0	0	0
Goldeye	0	0	0	0	0
Longear Sunfish	0	0	0	0	0
Mooneye	0	0	0	0	0
Paddlefish	0	0	0	0	0
Black/White Crappie	0	0	0	0	0
Quillback	0	0	0	0	0
Redear Sunfish	0	0	0	0	0
River Carpsucker	0	0	0	0	0
Sauger	0	0	0	0	0
Smallmouth Buffalo	0	0	0	0	0
Spotted Bass	0	0	0	0	0
Shortnose Gar	0	0	0	0	0
Striped Bass	0	0	0	0	0
Warmouth	0	0	0	0	0
White Bass	0	0	0	0	0
Total	34	3	6	3	46

Table 2-25. Percent species composition at each habitat type in the Smithland Pool of the Ohio River during session 2 of 2002-2003 (April 2003).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Blue Catfish	58.80	33.30	16.70	0.00	47.83
Bighead Carp	0.00	0.00	0.00	0.00	0.00
Bluegill	0.00	0.00	0.00	0.00	0.00
Channel Catfish	2.90	33.30	16.70	33.30	8.70
Common Carp	0.00	0.00	0.00	0.00	0.00
Emerald Shiner	0.00	0.00	0.00	0.00	0.00
Flathead Catfish	2.90	0.00	16.70	0.00	4.35
Flier	0.00	0.00	0.00	0.00	0.00
Freshwater Drum	35.30	33.30	50.00	66.70	39.13
Gizzard Shad	0.00	0.00	0.00	0.00	0.00
Goldeye	0.00	0.00	0.00	0.00	0.00
Longear Sunfish	0.00	0.00	0.00	0.00	0.00
Mooneye	0.00	0.00	0.00	0.00	0.00
Paddlefish	0.00	0.00	0.00	0.00	0.00
Black/White Crappie	0.00	0.00	0.00	0.00	0.00
Quillback	0.00	0.00	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00	0.00
River Carpsucker	0.00	0.00	0.00	0.00	0.00
Sauger	0.00	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00	0.00
Shortnose Gar	0.00	0.00	0.00	0.00	0.00
Striped Bass	0.00	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.00	0.00
White Bass	0.00	0.00	0.00	0.00	0.00

Table 2-26. Mean number of fish caught per hour of electrofishing among sites of the Smithland Pool during session 2 of 2002-2003 (April 2003).

	Habitat types			
Species	Artificial	Island	Main	Tributary
Bigmouth Buffalo	0.00	0.00	0.00	0.00
Blue Catfish	40.00	2.40	3.00	0.00
Bighead Carp	0.00	0.00	0.00	0.00
Bluegill	0.00	0.00	0.00	0.00
Channel Catfish	2.00	2.40	3.00	4.00
Common Carp	0.00	0.00	0.00	0.00
Emerald Shiner	0.00	0.00	0.00	0.00
Flathead Catfish	2.00	0.00	3.00	0.00
Flier	0.00	0.00	0.00	0.00
Freshwater Drum	24.00	2.40	9.00	3.67
Gizzard Shad	0.00	0.00	0.00	0.00
Goldeye	0.00	0.00	0.00	0.00
Longear Sunfish	0.00	0.00	0.00	0.00
Mooneye	0.00	0.00	0.00	0.00
Paddlefish	0.00	0.00	0.00	0.00
Black/White Crappie	0.00	0.00	0.00	0.00
Quillback	0.00	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00
River Carpsucker	0.00	0.00	0.00	0.00
Sauger	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.00	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00
Shortnose Gar	0.00	0.00	0.00	0.00
Striped Bass	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.00
White Bass	0.00	0.00	0.00	0.00
Total	22.67	1.22	6.00	0.94

Table 2-27. Total number of fish caught at each habitat type in the Smithland Pool of the Ohio River during session 3 of 2002-2003 (June 2003).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0	0	0	0	0
Blue Catfish	82	8	21	5	116
Bighead Carp	0	0	0	0	0
Bluegill	0	0	0	0	0
Channel Catfish	4	1	2	0	7
Common Carp	0	0	3	0	3
Emerald Shiner	0	0	0	0	0
Flathead Catfish	0	0	3	0	3
Flier	0	0	0	0	0
Freshwater Drum	9	3	23	1	36
Gizzard Shad	0	0	0	0	0
Goldeye	1	0	0	0	1
Longear Sunfish	0	0	0	0	0
Mooneye	0	0	0	0	0
Paddlefish	1	0	1	0	2
Black/White Crappie	0	0	0	0	0
Quillback	0	0	0	0	0
Redear Sunfish	0	0	0	0	0
River Carpsucker	1	0	0	0	1
Sauger	0	0	0	0	0
Smallmouth Buffalo	0	0	0	0	0
Spotted Bass	0	0	0	0	0
Shortnose Gar	0	0	0	0	0
Striped Bass	0	0	0	0	0
Warmouth	0	0	0	0	0
White Bass	0	0	0	0	0
Total	98	12	53	6	169

Table 2-28. Percent species composition at each habitat type in the Smithland Pool of the Ohio River during session 3 of 2002-2003 (June 2003).

	Habitat types				
Species	Artificial	Island	Main	Tributary	Total
Bigmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Blue Catfish	83.70	66.70	39.60	83.30	68.64
Bighead Carp	0.00	0.00	0.00	0.00	0.00
Bluegill	0.00	0.00	0.00	0.00	0.00
Channel Catfish	4.10	8.30	3.80	0.00	4.14
Common Carp	0.00	0.00	5.70	0.00	1.78
Emerald Shiner	0.00	0.00	0.00	0.00	0.00
Flathead Catfish	0.00	0.00	5.70	0.00	1.78
Flier	0.00	0.00	0.00	0.00	0.00
Freshwater Drum	9.20	25.00	43.40	16.70	21.30
Gizzard Shad	0.00	0.00	0.00	0.00	0.00
Goldeye	1.00	0.00	0.00	0.00	0.59
Longear Sunfish	0.00	0.00	0.00	0.00	0.00
Mooneye	0.00	0.00	0.00	0.00	0.00
Paddlefish	1.00	0.00	1.90	0.00	1.18
Black/White Crappie	0.00	0.00	0.00	0.00	0.00
Quillback	0.00	0.00	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00	0.00
River Carpsucker	1.00	0.00	0.00	0.00	0.59
Sauger	0.00	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.00	0.00	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00	0.00
Shortnose Gar	0.00	0.00	0.00	0.00	0.00
Striped Bass	0.00	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.00	0.00
White Bass	0.00	0.00	0.00	0.00	0.00

Table 2-29. Mean number of fish caught per hour of electrofishing among sites of the Smithland Pool during session 3 of 2002-2003 (June 2003).

	Habitat types			
Species	Artificial	Island	Main	Tributary
Bigmouth Buffalo	0.00	0.00	0.00	0.00
Blue Catfish	30.00	7.80	21.60	15.00
Bighead Carp	0.00	0.00	0.00	0.00
Bluegill	0.00	0.00	0.00	0.00
Channel Catfish	5.00	3.00	3.00	0.00
Common Carp	0.00	0.00	3.40	0.00
Emerald Shiner	0.00	0.00	0.00	0.00
Flathead Catfish	0.00	0.00	5.20	0.00
Flier	0.00	0.00	0.00	0.00
Freshwater Drum	4.50	4.50	22.13	3.00
Gizzard Shad	0.00	0.00	0.00	0.00
Goldeye	3.00	0.00	0.00	0.00
Longear Sunfish	0.00	0.00	0.00	0.00
Mooneye	0.00	0.00	0.00	0.00
Paddlefish	3.00	0.00	2.00	0.00
Black/White Crappie	0.00	0.00	0.00	0.00
Quillback	0.00	0.00	0.00	0.00
Redear Sunfish	0.00	0.00	0.00	0.00
River Carpsucker	3.00	0.00	0.00	0.00
Sauger	0.00	0.00	0.00	0.00
Smallmouth Buffalo	0.00	0.00	0.00	0.00
Spotted Bass	0.00	0.00	0.00	0.00
Shortnose Gar	0.00	0.00	0.00	0.00
Striped Bass	0.00	0.00	0.00	0.00
Warmouth	0.00	0.00	0.00	0.00
White Bass	0.00	0.00	0.00	0.00
Total	11.70	1.69	14.76	1.20

Table 2-30. Total combined catch and mean total length (mm) as a function of habitat type in Smithland Pool of the Ohio River during winter through late spring 2003.

	Number in Habitat						
Species	Artificial	Island	Main	Tributary	Total	Mean TL	SD
Bigmouth Buffalo	0	0	0	0	0	.	.
Blue Catfish	493	196	208	8	905	224.29	115.54
Bighead Carp	0	1	0	0	1	880.00	.
Bluegill	0	0	0	0	0	.	.
Channel Catfish	6	18	20	2	46	334.24	115.69
Common Carp	1	0	5	0	6	649.17	37.93
Emerald Shiner	0	0	0	0	0	.	.
Flathead Catfish	1	0	4	0	5	582.00	191.84
Flier	0	0	0	0	0	.	.
Freshwater Drum	197	209	377	36	819	239.96	88.90
Gizzard Shad	3	3	1	19	26	171.38	78.56
Goldeye	0	3	0	0	3	202.33	73.82
Longear Sunfish	0	1	0	0	1	114.00	.
Mooneye	0	2	2	0	4	207.00	62.78
Paddlefish	1	0	1	0	2	630.00	155.56
Black/White Crappie	0	0	1	0	1	224.00	.
Quillback	3	1	0	0	4	215.75	69.08
Redear Sunfish	0	0	0	0	0	.	.
River Carpsucker	7	0	1	0	8	323.75	110.50
Sauger	1	0	0	0	1	246.00	.
Smallmouth Buffalo	11	0	1	0	12	486.83	57.31
Spotted Bass	0	0	0	0	0	.	.
Shortnose Gar	0	1	0	0	1	168.00	.
Striped Bass	0	0	1	0	0	194.00	.
Warmouth	0	0	0	0	4	198.50	32.26
White Bass	1	0	0	0	1	337.00	.

Figure 2-1. Sites within Smithland Pool of the Ohio River during winter through spring 2002 and 2003.

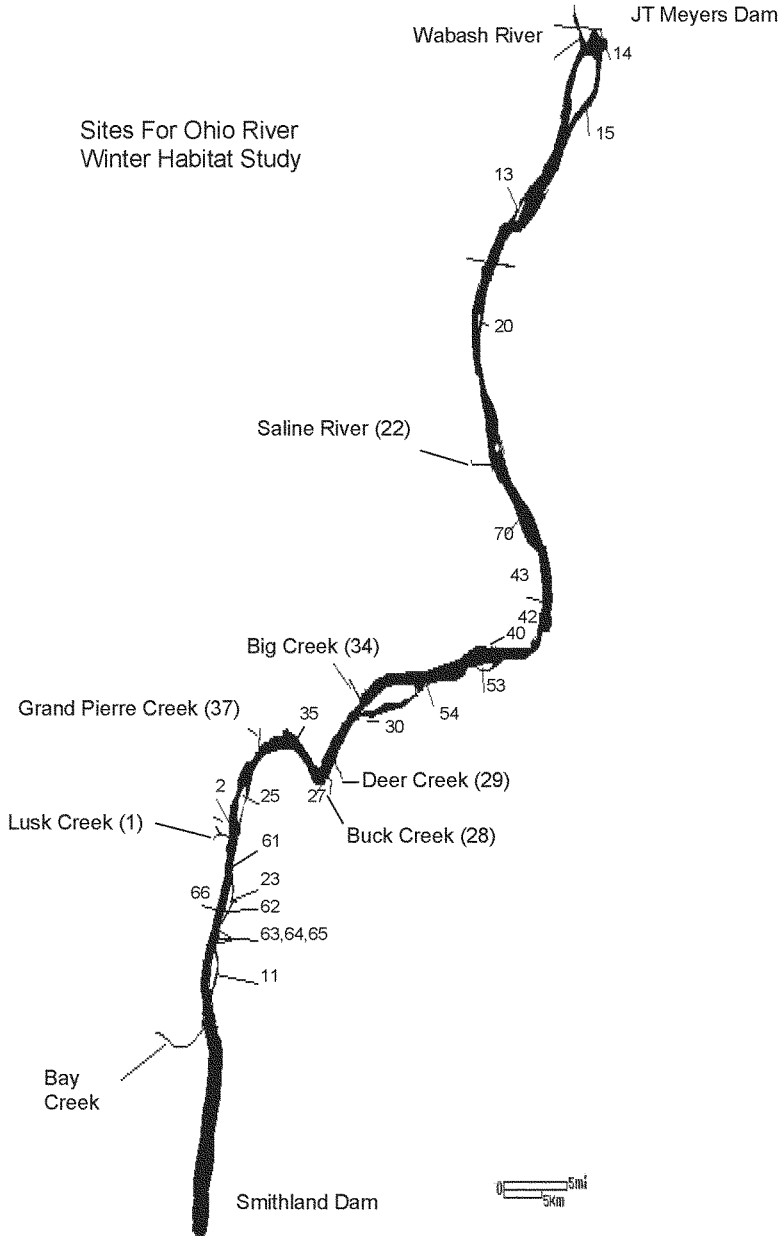


Figure 2-2. Daily discharge (ft^3/s; dashed line) and gage height (ft; solid line) during winter through spring 2002 and 2003 at a gauging station below Smithland Pool, Ohio River (USGS Metropolis, IL). Sampling could only occur during periods of low or normal flow.

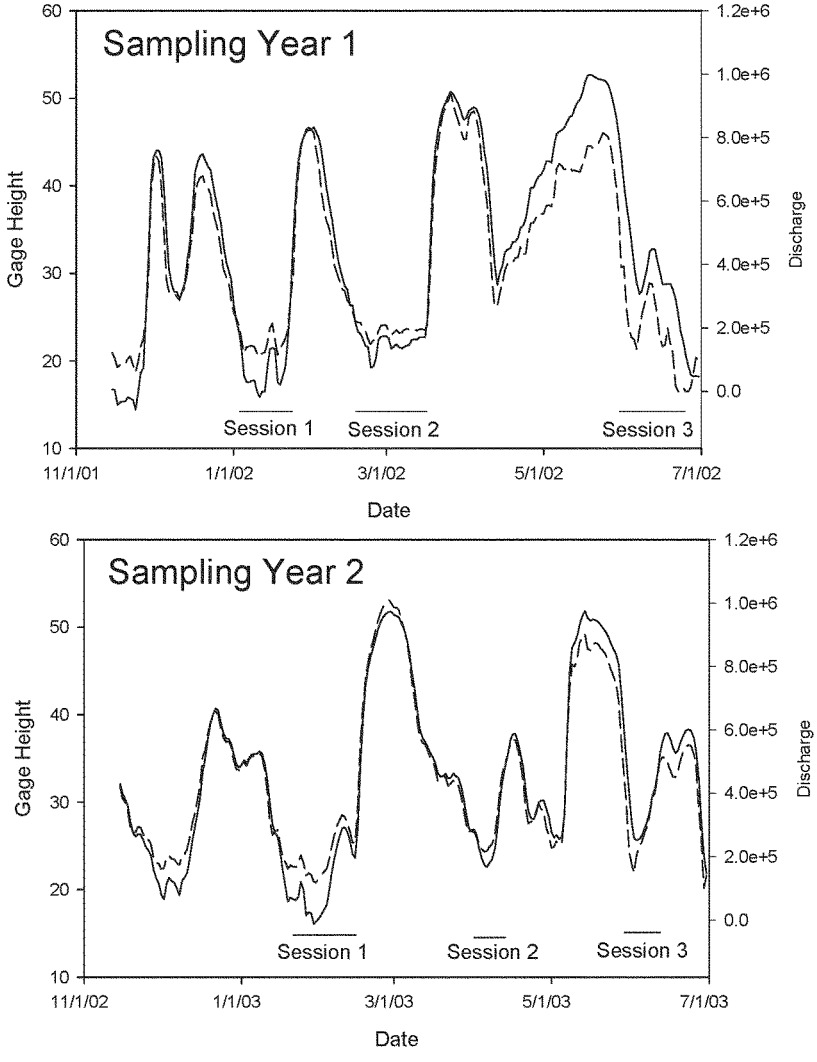


Figure 2-3. Water temperatures of the lower Ohio River during winter through spring 2002 and 2003. Bottom temperatures derive from the bottom of Smithland Pool. Bars above and below the trend line represent maximum and minimum daily temperatures. Surface temperatures derive from the Shawnee Fossil Power Plant below Smithland Dam. Lines on the bottom of each panel show sampling sessions.

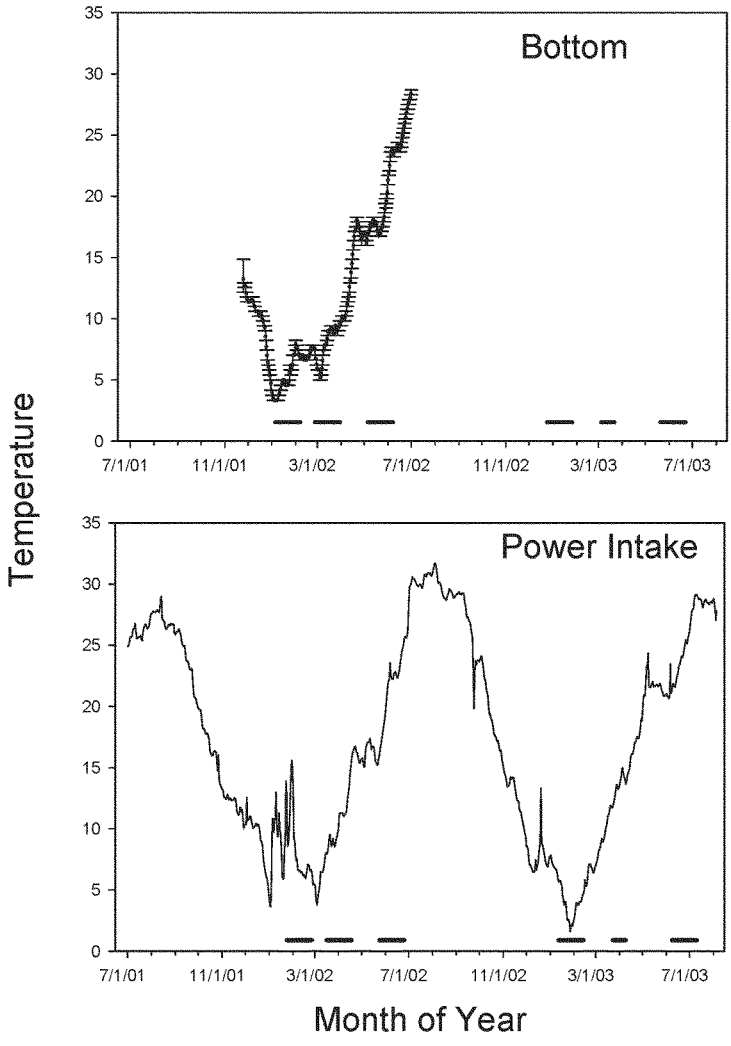


Figure 2-4. Results of a principle components analysis exploring how secchi depth, dissolved oxygen concentration, specific conductance, flow velocity, and temperature varied among sites in Smithland Pool, Ohio River during the winter 2002 and 2003 sampling sessions. The letter in each symbol represents artificial, island, tributary, or main. Note that low and > designations are relative only, often representing slight differences in quantities.

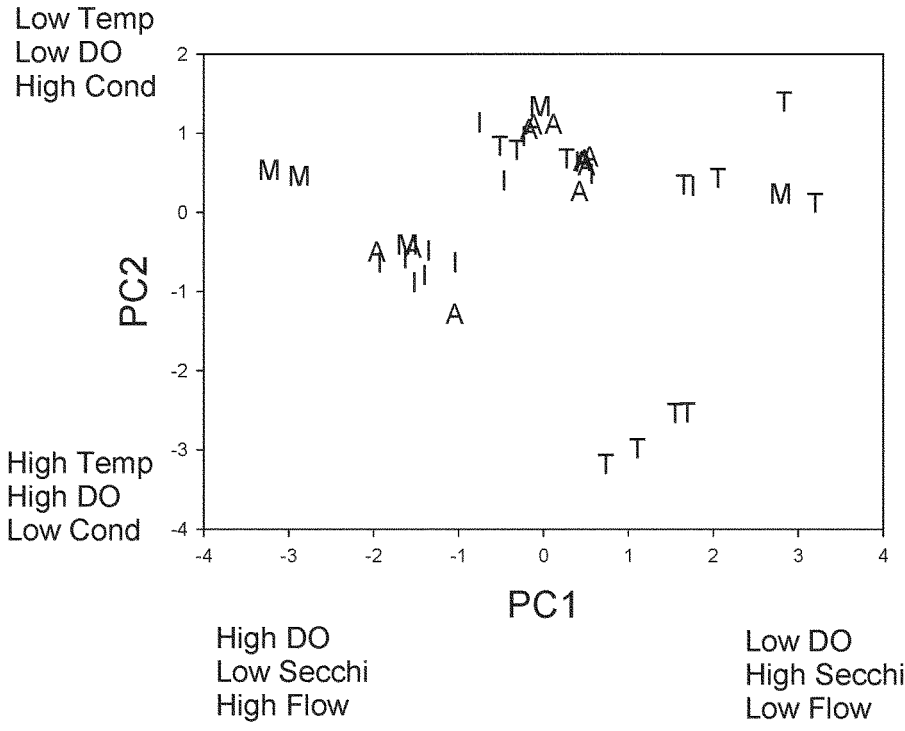


Figure 2-5. Mean number of freshwater drum, channel catfish, and blue catfish captured per hour with variable depth electrofishing in artificial, island, main, and tributary sites in Smithland Pool, Ohio River during winter through late spring 2002 and 2003. Statistics are results of a two way ANOVA exploring the effects of sampling session (Date) and habitat type (Habitat) on fish abundance.

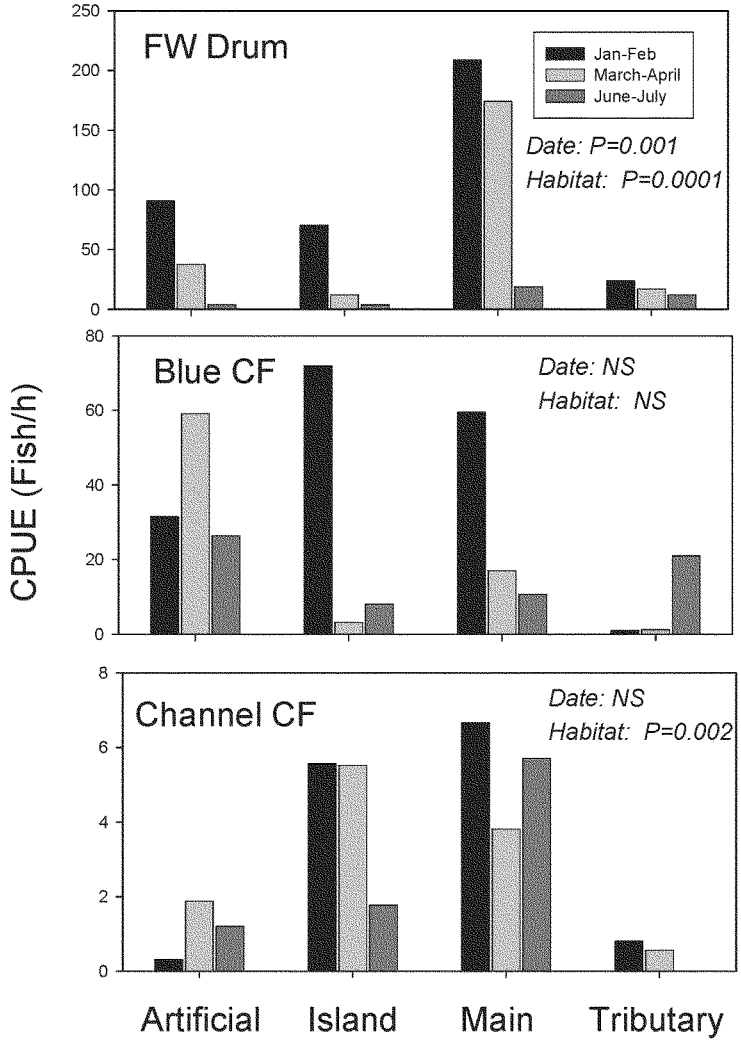


Figure 2-6. Results of principle components analysis for fish species assemblage structure as a function of habitat type (artificial, island, main channel, and tributary) and sampling session during winter through late spring 2002 in Smithland Pool, Ohio River. Relative abundances of all species sampled were included in the analysis (see Table XX). Major loadings were for species found in tributaries. Note that sites either in or adjacent to the main channel contained low numbers of these species. The arrows show that tributary assemblages became more similar to those in other sites by June. A similar pattern did not arise during winter 2003.

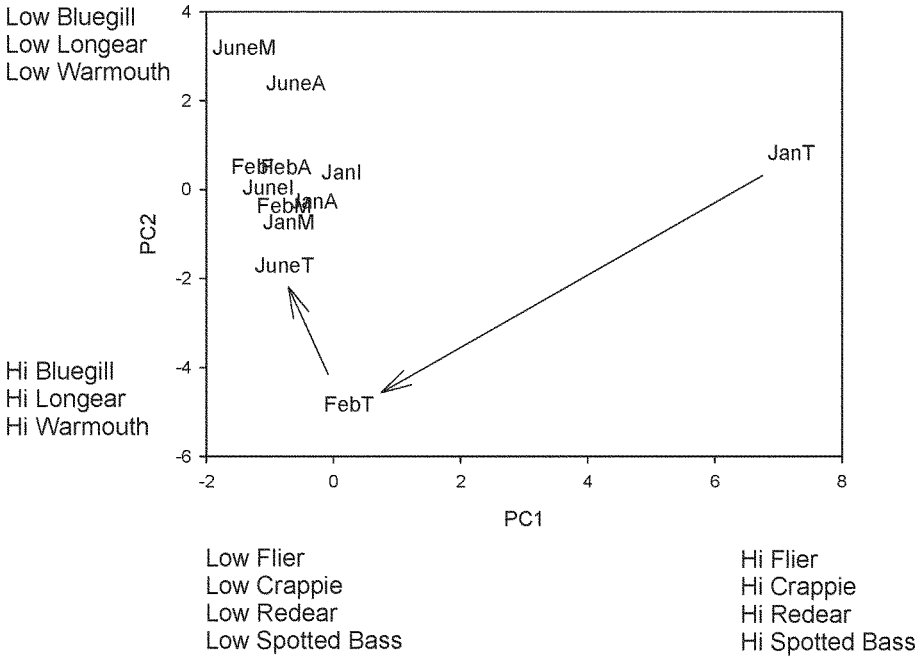


Figure 2-7. Results of non-metric multidimensional scaling ordination for Smithland Pool during winter 2002. Abundances (CPE) of the three fish species and habitat-specific water quality were quantified at each site. Water quality had little effect on the ordination. Conversely, freshwater drum were associated with main channel sites, blue catfish with artificial sites, and channel catfish with island sites. No structure was detected in the 2003 data set.

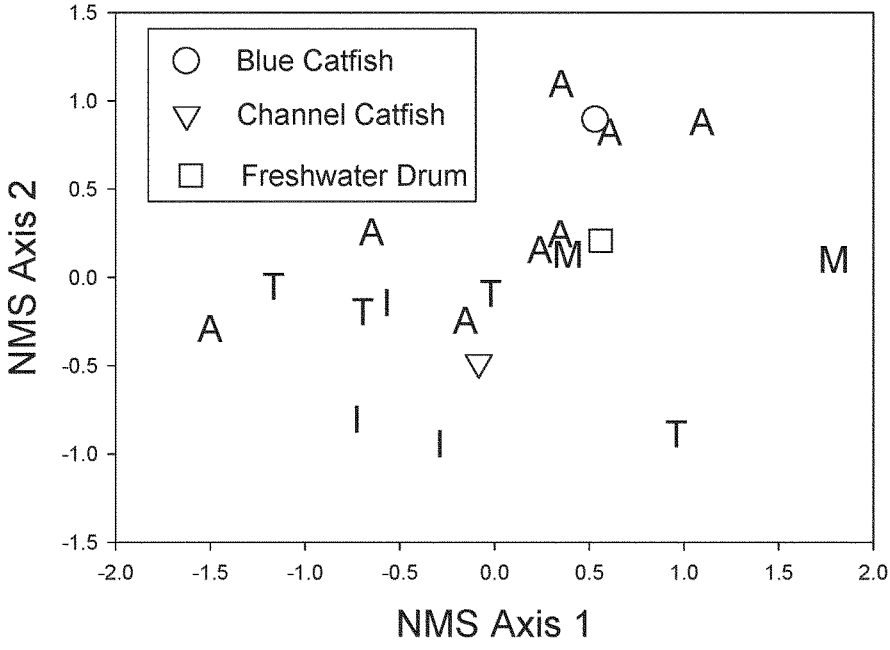


Figure 2-8. Mean total length (mm) of freshwater drum, channel catfish, and blue catfish in artificial, island, main, and tributary sites during winter through late spring 2002 and 2003 in Smithland Pool, Ohio River. An ANOVA for freshwater drum revealed that fish in tributary sites were smaller than at other sites.

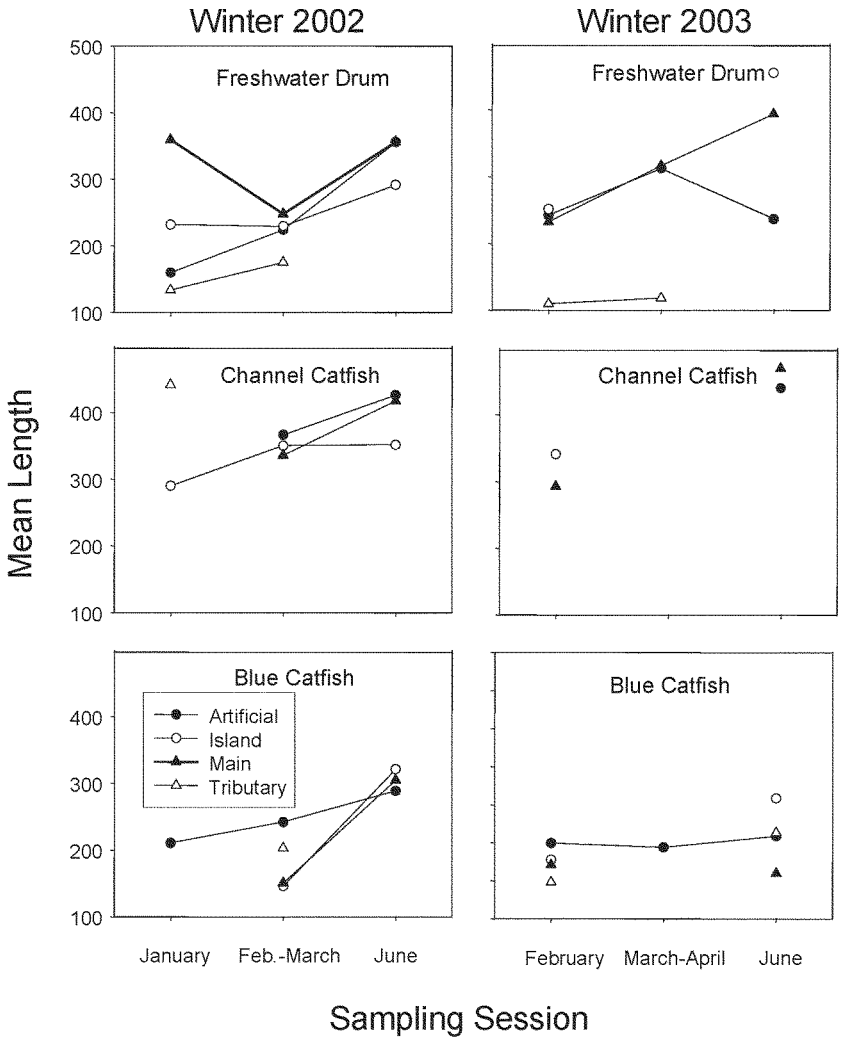


Figure 2-9. Number of species during winter through spring 2002 and 2003 as a function of temperature in Smithland Pool, Ohio River.

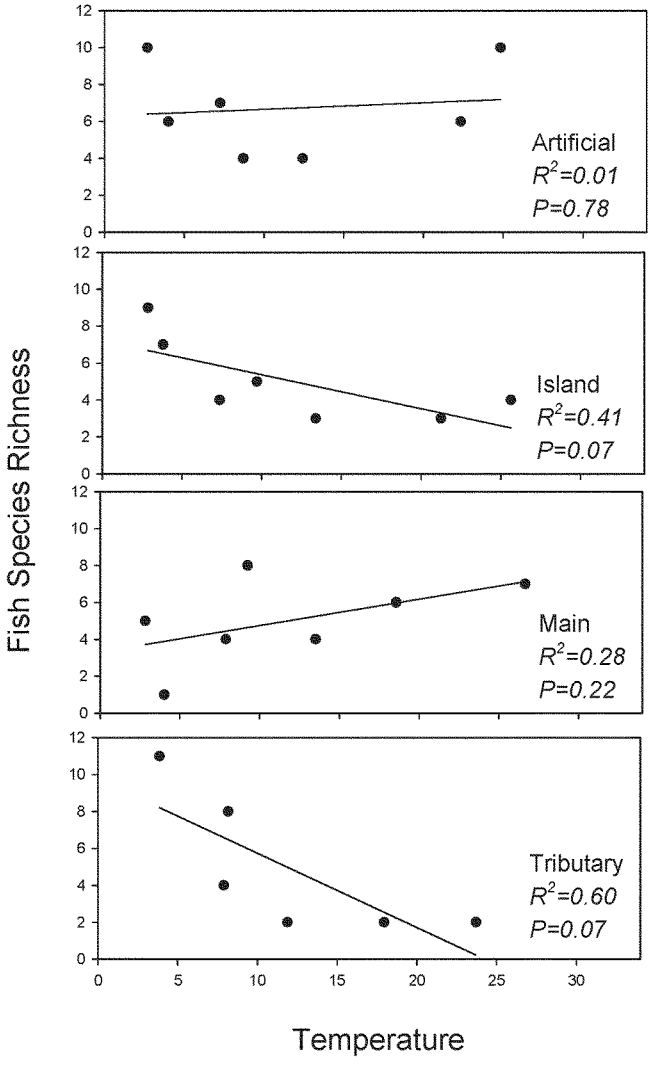


Figure 2-10. Number of species during winter through spring 2002 and 2003 as a function of dissolved oxygen concentration (mg/L) in Smithland Pool, Ohio River.

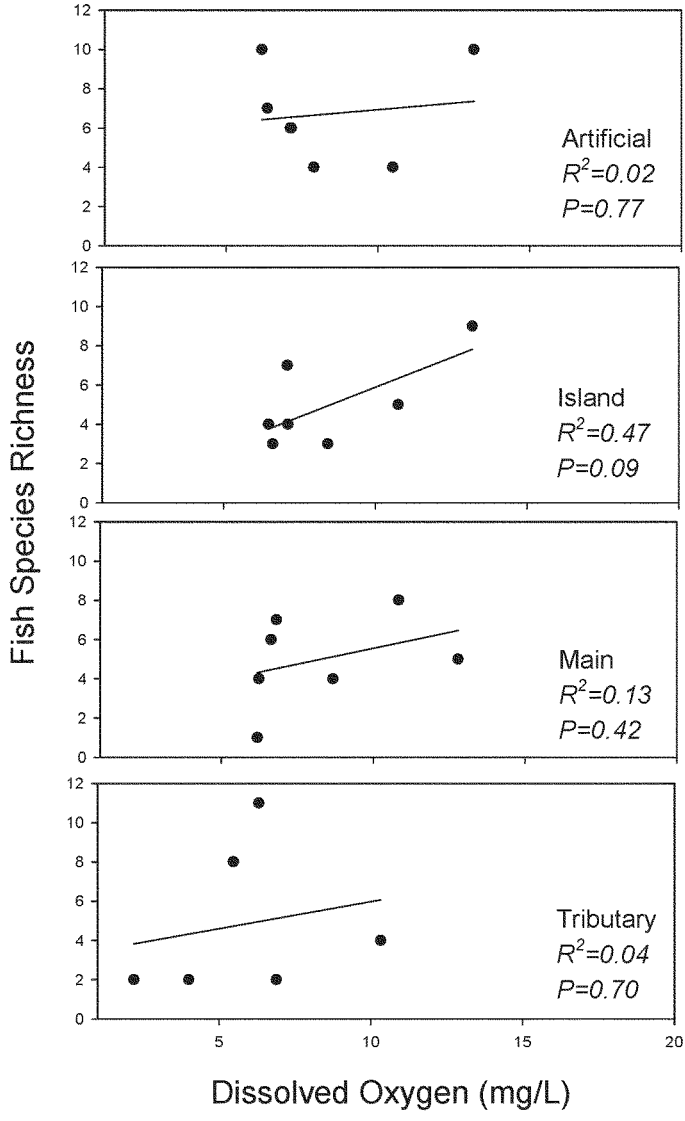


Figure 2-11. Number of species during winter through spring 2002 and 2003 as a function of flow (m/s) in Smithland Pool, Ohio River.

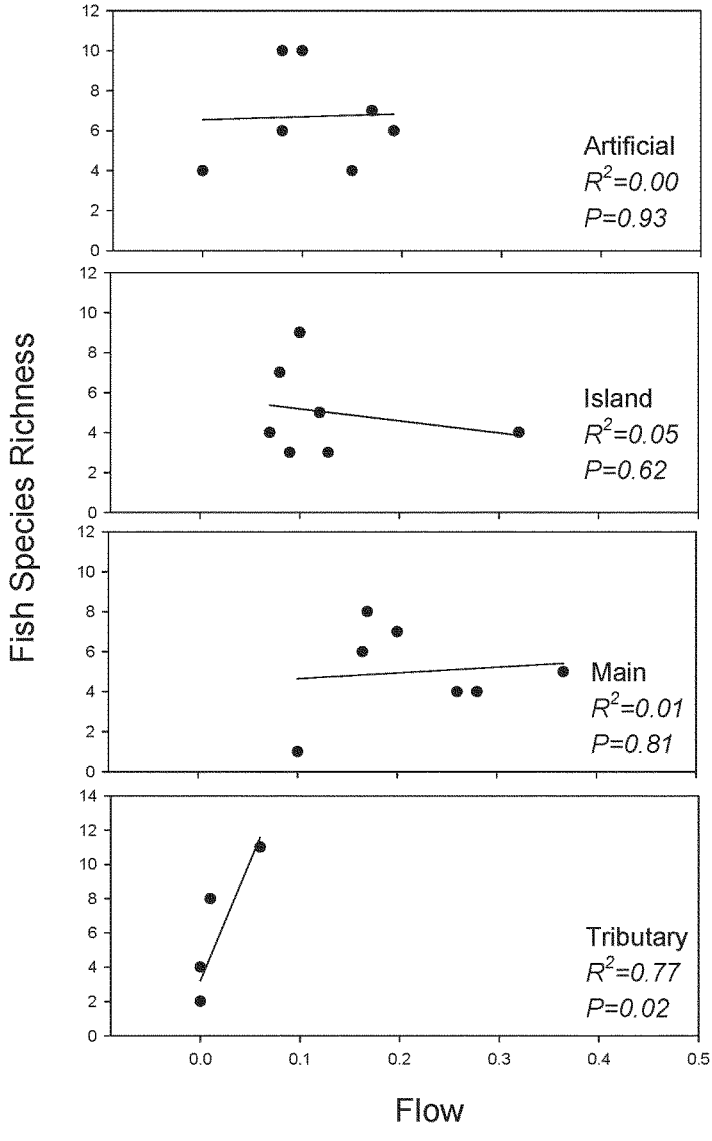


Figure 2-12. Length at age for freshwater drum, channel catfish, crappie, and white bass in Smithland Pool, Ohio River during winter through late spring 2002 (solid symbols) and 2003 (open symbols).

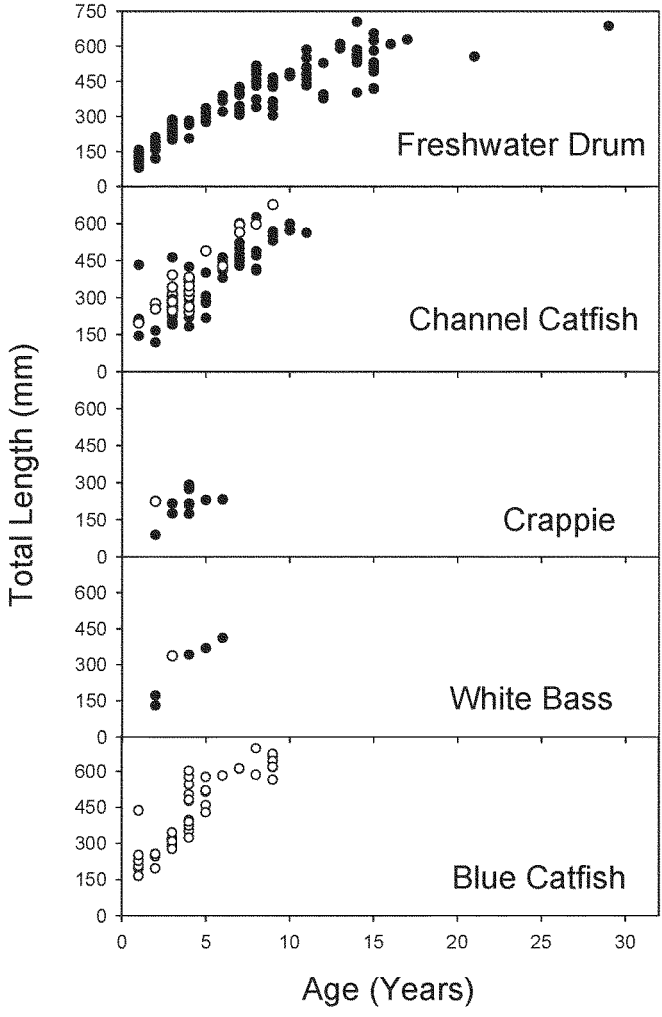


Figure 2-13. Length frequency distribution for freshwater drum in Smithland Pool, Ohio River during winter through spring 2002.

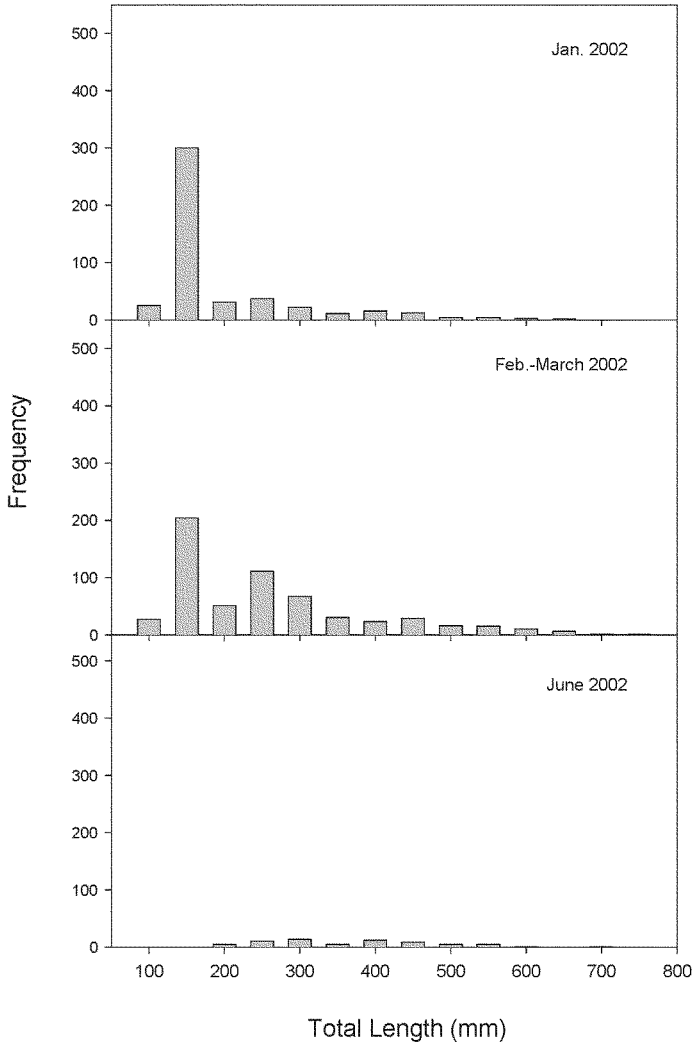


Figure 2-14. Length frequency distribution for freshwater drum in Smithland Pool, Ohio River during winter through spring 2003.

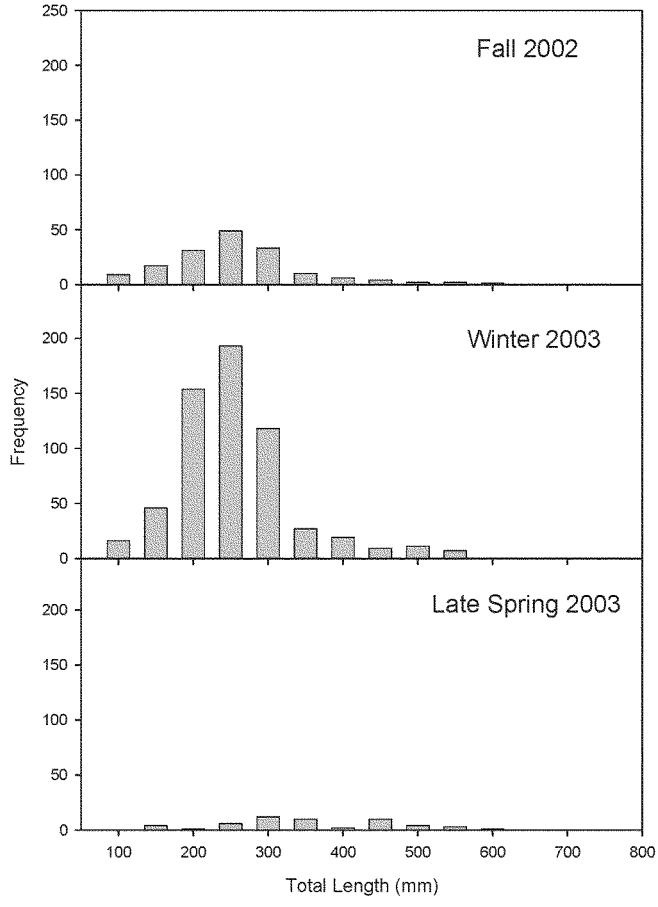


Figure 2-15. Relative weights (Wr) of freshwater drum sampled during three periods in Smithland Pool, Ohio River during winter 2002.

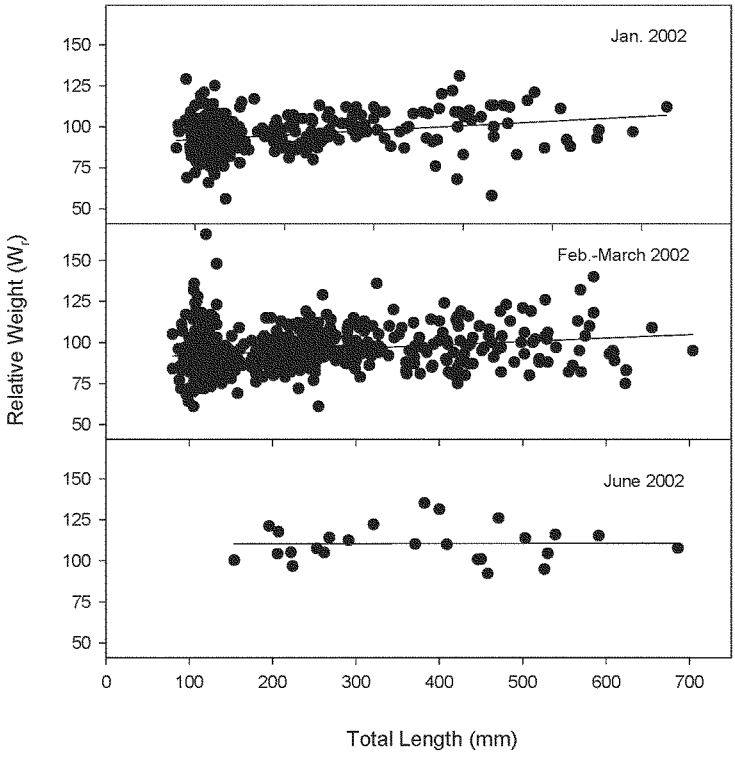


Figure 2-16. Relative weights (Wr) of freshwater drum sampled during four periods in Smithland Pool, Ohio River during winter 2003.

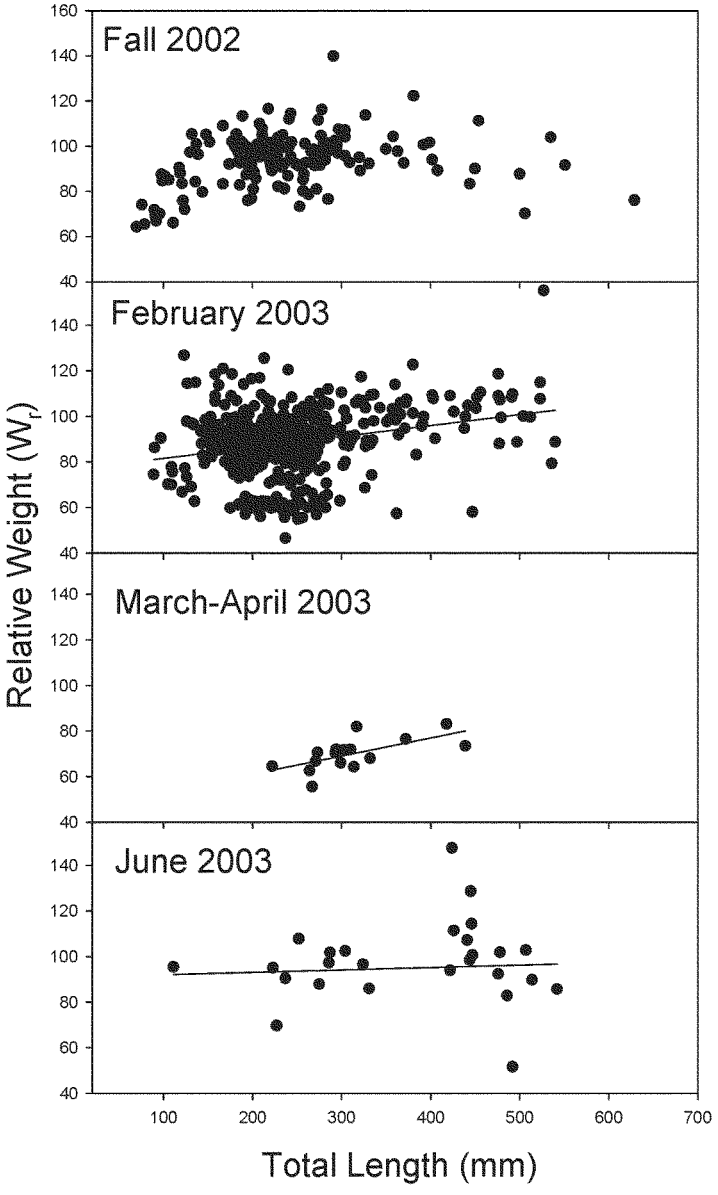


Figure 2-17. Proportion of freshwater drum with empty stomachs as a function of 50 mm length class during the first two sampling sessions of winter 2002 in Smithland Pool, Ohio River. Each length class is comprised of 3-8 individuals.

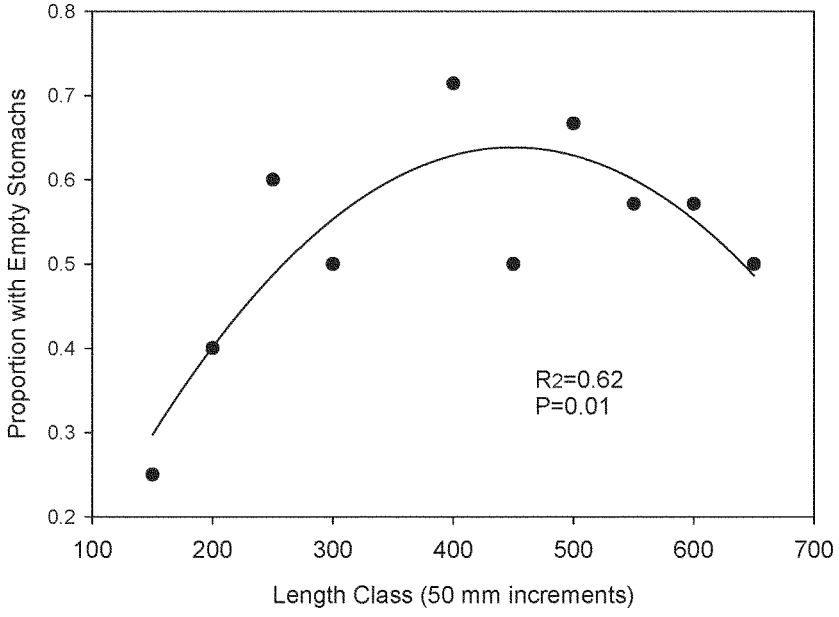


Figure 2-18. Length frequency distribution for channel catfish in the Smithland Pool of the Ohio River during winter through late spring 2002.

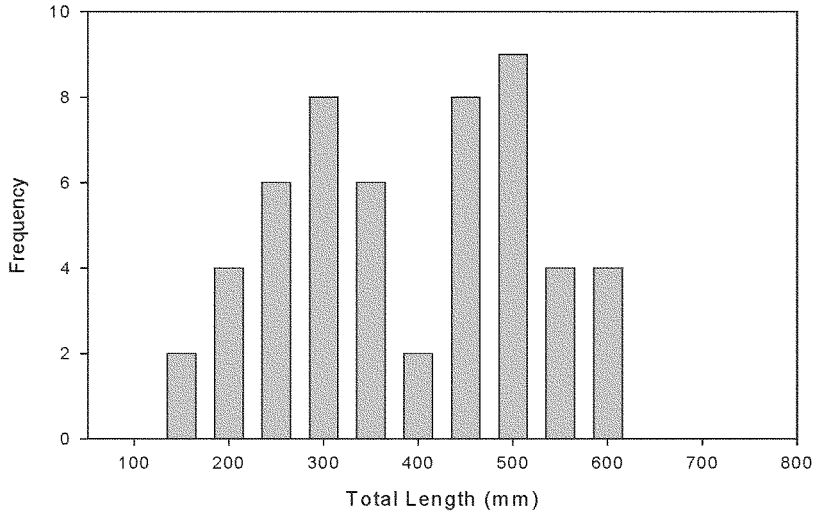


Figure 2-19. Length frequency distribution for channel catfish in the Smithland Pool of the Ohio River during winter through late spring 2003.

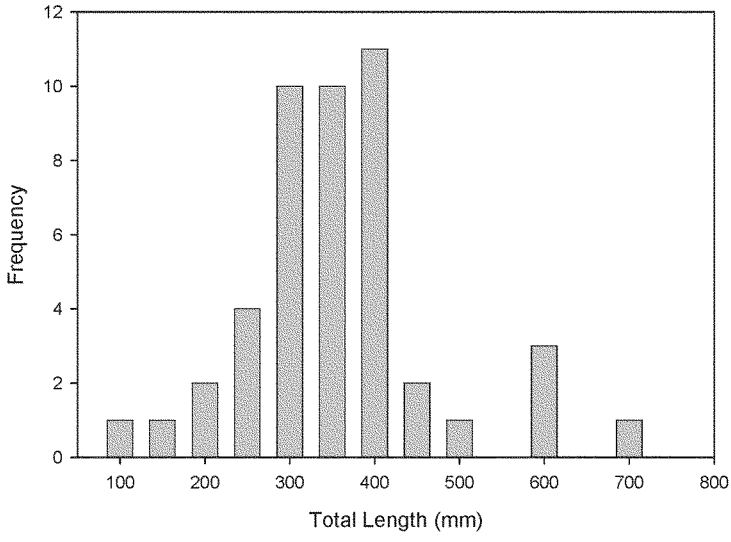


Figure 2-20. Relative weight (Wr) as a function of total length of channel catfish during winter through late spring 2002 in Smithland Pool, Ohio River.

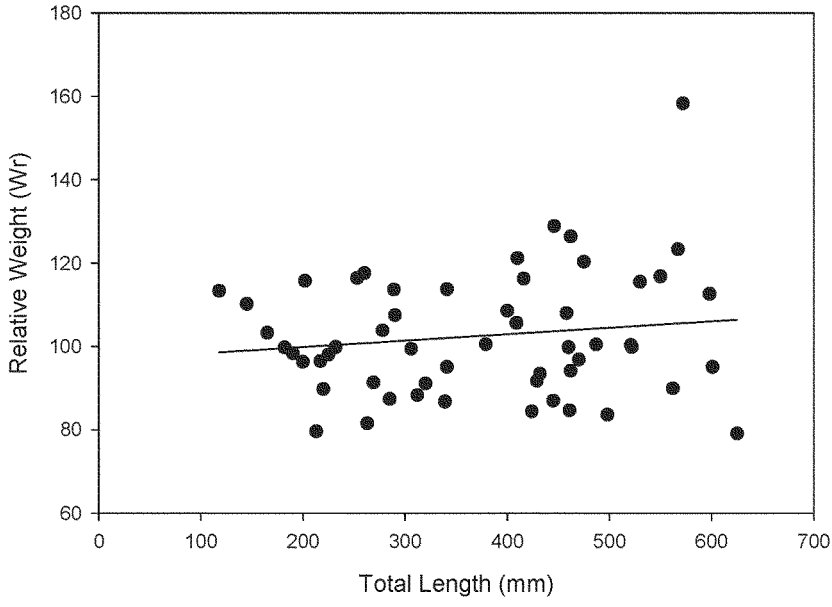


Figure 2-21. Relative weight (Wr) as a function of total length of channel catfish during fall 2002 through late spring 2003 in Smithland Pool, Ohio River.

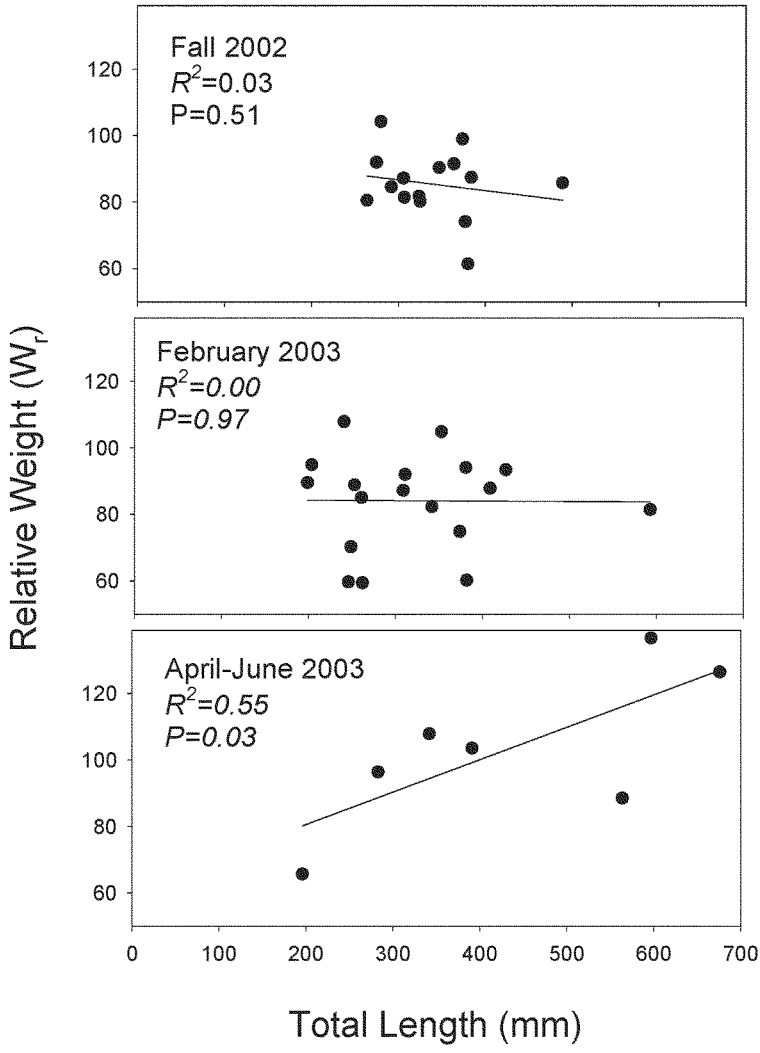


Figure 2-22. Length frequency distribution for blue catfish in the Smithland Pool of the Ohio River during winter through late spring 2002.

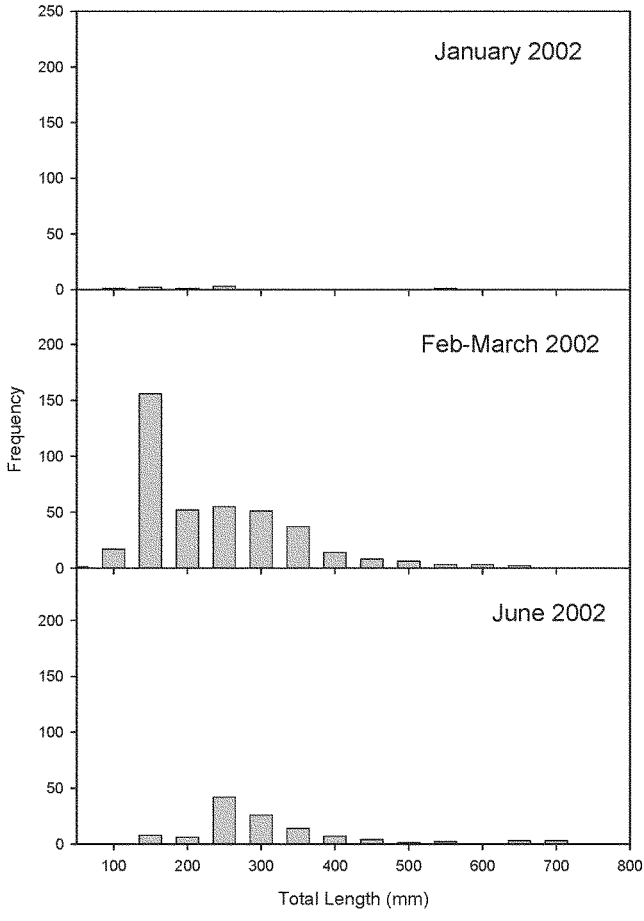


Figure 2-23. Length frequency distribution for blue catfish in the Smithland Pool of the Ohio River during winter through late spring 2003.

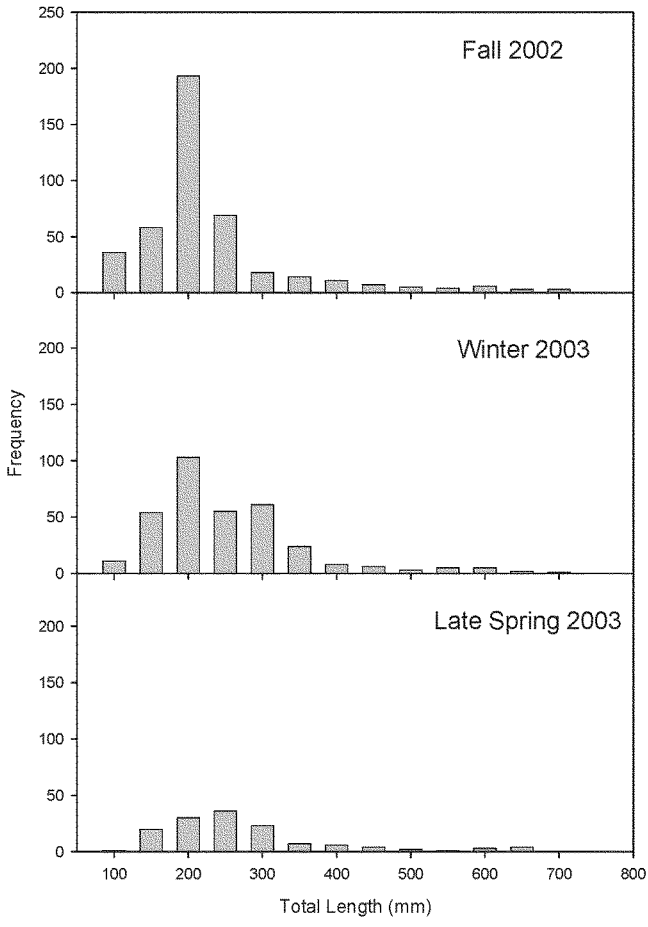


Figure 2-24. Blue catfish lengths versus weights during winter 2002. An analysis of covariance (ANCOVA) revealed that intercepts of lines differed among dates, with the lowest intercept occurring during the June 2002 sampling period.

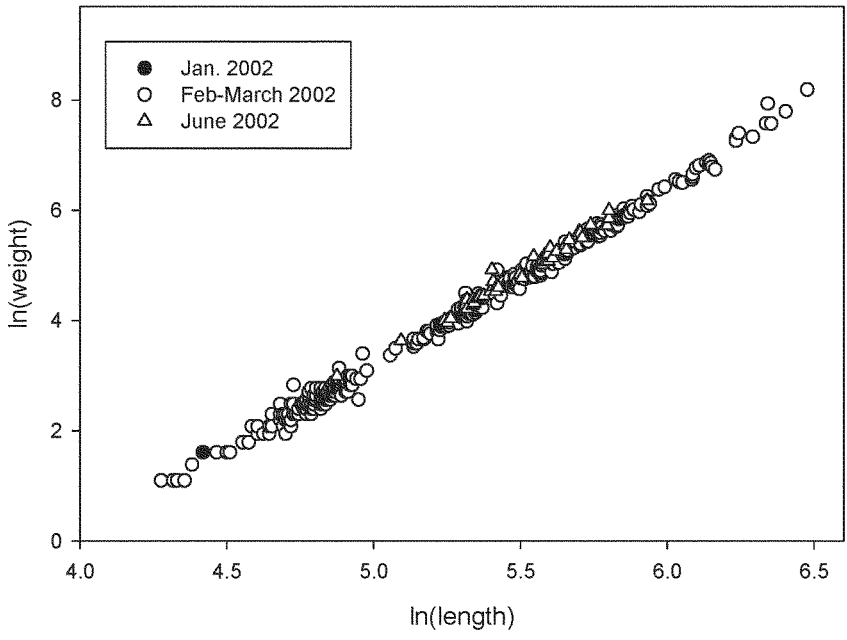
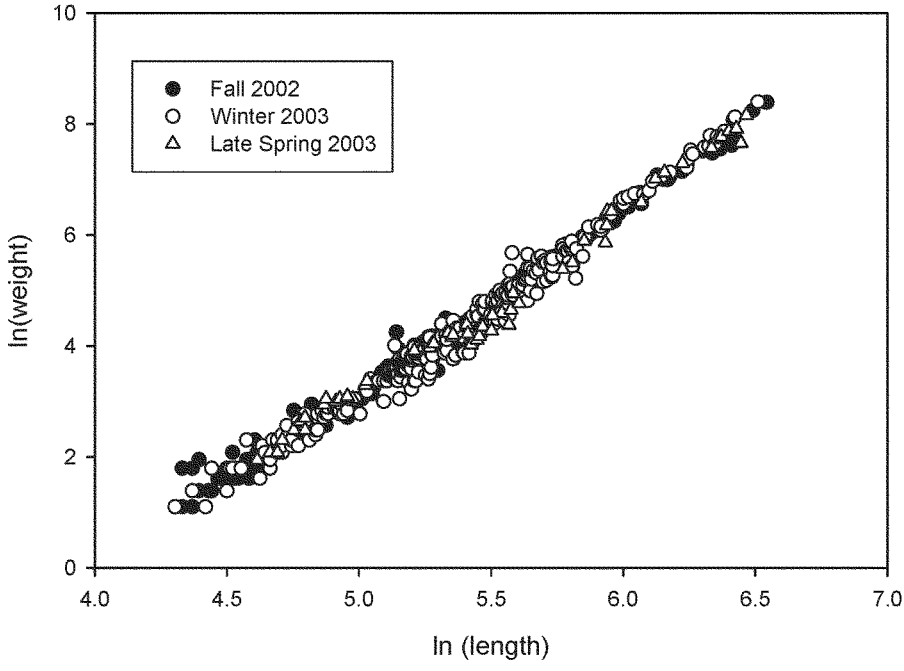


Figure 2-25. Blue catfish lengths versus weights during fall 2002 through winter 2003. An analysis of covariance (ANCOVA) revealed that intercepts of lines differed among dates, with the lowest intercept occurring during the fall 2002 sampling period.



Chapter 3 – Belleville Pool Field Sampling 2001-2003

Stuart Welsh, Kyle J. Hartman, and Ben Lenz, West Virginia University

INTRODUCTION

Fishes enter a torpor-like state in winter (Crawshaw 1984) where metabolic rates and consequently, respiration and activity rates are low (Carlson 1992, Cunjak 1996, Bodensteiner and Lewis 1992). The inability of a fish to expend energy in cold temperatures makes them susceptible to adverse physiochemical conditions, such as low dissolved oxygen concentrations and strong current velocities (Cunjak 1996). Mortality rates of fishes can be high during low water temperatures in winter (Bodensteiner and Lewis 1992, Lyons 1997); however, fishes select refuge habitats to survive winter (Johnson et al. 1998). Given the link between winter temperature and fish mortality, fishery managers need to locate and protect winter refuge habitats.

Despite early calls for wintertime fish research (Hubbs and Trautman 1935), little is known about winter habitat preferences of fishes in temperate river systems (Hubbs and Trautman 1935, Nielsen et al. 1986, Sheehan et al. 1994). Sheehan et al. (1994) and Garvey et al. (2002; Chapter 1) reviewed the literature on species tolerance to velocity and temperature in large rivers, and reported low tolerance to high velocities at temperatures below 4 °C. Species should partition habitat during winter largely as a function of their relative tolerance to winter temperatures, flow velocity, and minimum dissolved oxygen concentration (Johnson et al. 1998). In our study on Belleville Pool, macrohabitats of the Ohio River provide habitat-specific combinations of these three important factors. We identified five main habitat types (Table 3-1, see Vallazza et al.

1994 and Cray 1999 for similar delineations). Based on research cited herein and in Sheehan et al. (1994) and Garvey et al. (2002; Chapter 1), backwaters, island habitats, tributary confluences, and deep hole habitats provide winter refuges for riverine fishes.

Objectives

Our objective was to (1) determine species/habitat associations among main channel, tributary mouth, backwater, head of island, tail of island, and deep hole habitats during winter in Belleville Pool, Ohio River. A secondary objective was to determine abiotic habitat characteristics associated with fish habitat use. This research was conducted as partial fulfillment of a Master's degree (see completed thesis, Appendix 1).

LITERATURE REVIEW

Winter habitats of fishes in large rivers

Physiochemical tolerance limits influence range distributions and habitat use. Within the range of a species, seasonal variations in physiochemical factors are often extreme, such as cold winter conditions in temperate climates. During seasonal extremes, animals select refuge habitats where physiochemical factors are unlikely to exceed tolerance limits. In large temperate river systems, extremely low water temperatures during winter coupled with high flows increase mortality rates of fishes (Bodensteiner and Lewis 1992, Lyons 1997). Low levels of dissolved oxygen also increase mortality of fishes, and occur typically during ice-cover of backwater areas. Many fishes forage infrequently during cold winter extremes, and select refuges that minimize energy depletion. Fishes often increase fat-reserves before winter; hence, reducing mortality associated with energy depletion. However, energy reserves may not suffice given long

winters or energy expenditures due to disturbance, such as variation in river flows or boat traffic (Nielsen et al. 1986).

Temperature and flow

During winter, riverine fishes select habitats with relatively high temperatures and low flows. Riverine fishes overwinter in velocity shelters (Logsdon 1993, Bodensteiner and Lewis 1994, Johnson et al. 1998) and areas with warmer temperatures and lower flows than mainstem river sections, such as off-channel coves, marinas, embayments and industrial warm-water outflows (Raibley et al. 1997, Sheehan et al. 1994, Knights et al. 1995, Gent et al. 1995). Also, backwater areas with relatively warmer temperatures and lower flows provide winter habitats (Bodensteiner and Lewis 1992, Raibley et al. 1997, Sheehan and Rasmussen 1999).

Sheehan et al (1990) examined temperature and flow requirements for several fishes common in the Ohio River, such as gizzard shad (*Dorosoma cepedianum)*, channel catfish (*Ictalurus punctatus*), and freshwater drum (*Aplodinotus grunniens*). Gizzard shad, channel catfish, and freshwater drum occupy relatively low velocity areas during winter (Heese and Newcomb 1982, Newcomb 1989, Sheehan et al 1990, Bodensteiner and Lewis 1994, Logsdon 1993). Gizzard shad are vulnerable to winter die-offs during low water temperatures (Miller 1960). Garvey (2002; Chapter 1) reviewed over 300 articles on the winter ecology of riverine fishes and reported temperature preferences of • • 4 °C for many species in large rivers, such as green sunfish (*Lepomis cyanellus*), bluegill (*Lepomis macrochirus*), and freshwater drum. Some species, such as channel catfish, black crappie (*Pomoxis nigromaculatus*), and walleye (*Stizostedion vitreum*), can maintain swimming abilities at temperatures < 4 °C (Sheehan et al. 1990). Temperature

and flow preferences during winter, and swimming abilities during low temperatures are unknown for most riverine fishes.

Dissolved oxygen

Abiotic factors other than water temperature and flow velocity likely influence the suitability of winter habitats. Backwater areas can become anoxic and unsuitable as overwintering areas (Bodensteiner and Lewis 1992, Knights et al. 1995, Johnson et al. 1998). Low DO levels can result in fish die-offs when backwater areas become isolated from the main channel during low water levels in winter (Raibley et al. 1997). In the West Virginia section of the Ohio River, dissolved oxygen is reduced by water pollution near cities, but normally remains above critical levels (Pearson and Krumholz 1984).

Gear Use and Comparisons

Passive gears, such as hoop nets, gill nets, traps (Hubert 1996) and active gears , such as electrofishers and trawls (Hayes et al. 1996) are used to sample fishes in large rivers. Gear use should reflect seasonal variation in fish behavior. For example, passive gears may be ineffective for inactive fishes during winter. Bottom trawling in large rivers is complicated by benthic debris, whereas electrofishing near the surface fails to sample benthic areas. Most fishes are inactive and benthic during winter, so active and benthic-oriented gears are logical choices, such as a variable-depth AC electrofisher (Newcomb 1989). Regardless of gear type and seasonal affects, detection probabilities and sampling efficiency are low for most riverine fishes (Thompson et al. 1998).

Sampling Efficiency

Sampling efficiency, the percent of the population captured by sampling, is difficult to quantify. Sampling efficiency of a gear type can be examined by sampling with other gears or toxicants. Few gears, however, provide a 100% probability of detecting all individuals within an area of an open system, such as a single habitat type within a large river. Results from gear comparisons are often not definitive. For example, one could interpret low captures from two gears as evidence for low fish abundance or one could argue that both gears sample inefficiently.

Conductivity, flow velocity, water temperature, and biological factors affect electrofishing efficiency. Low conductivity decreases electrofishing efficiency (Kolz et al. 1998). High flow velocity moves fishes away from netters and reduces capture success. Additionally, species have variable vulnerability to electrofishing because of morphological, physiological, and behavioral differences (Kolz et al. 1998). Small fishes are less vulnerable to electrofishing (Reynolds 1996).

Electrofishing gears and configurations, such as AC versus DC and electrode position, also influence sampling efficiency. In variable-depth AC electrofishers, the electrical field occurs between electrodes rather than between boat and electrodes as in traditional DC electrofishers. If electrodes from variable-depth AC boats are near the river bottom, then the gear becomes specific to bottom habitat (because of electrode placement), so fishes in the water column are less vulnerable. In contrast, DC electrofishing boats typically deploy electrodes near the surface, and are ineffective at sampling benthic areas in deep habitats.

METHODS

Study area description

The Belleville Pool of the Ohio River, created by Belleville Lock and Dam (rkm 328.1), is bound upstream by Willow Island Lock and Dam (rkm 260.2). The 67.9 km pool averages 404.5 m wide, 7.3 m deep, and comprises 2850 ha of surface area (ORSANCO 1994). The deepest section of the pool (15 m) lies directly upstream of Belleville Lock and Dam. A navigation channel (2.7 m deep) is maintained for commercial barge traffic by the United States Army Corps of Engineers (USACE) (ORSANCO 1994). Two other large rivers, the Muskingum River in Ohio, and the Little Kanawha River in West Virginia are navigable tributaries of the Ohio River.

The riparian zone is a mixture of hardwood forests, urban and industrial frameworks, and agricultural settings. Most large floodplains near Belleville Pool are heavily urbanized. The two largest population centers along Belleville Pool are Parkersburg, WV (confluence of the Little Kanawha and Ohio rivers) and Marietta, OH (junction of Muskingum and Ohio rivers). Riparian areas unaffected by human settlement are steep forested hillsides that restrict lateral flow away from the mainstem Ohio River.

Habitat type classifications

We classified habitat types as main channel, deep hole, backwater, island head, island tail, tributary, wing dam, and embayment. Vallazza et al. (1994) and Cray (1999) discussed similar habitats, and our classification scheme (see Table 3-1) is further described below. Main channel habitats are used as commercial navigation routes, and typically have shallow near-shore areas and deeper mid-channel sections. Deep hole habitats are deep areas created by dredging or natural scour within main channel or

backwater areas. Backwater, island head, and island tail habitats are associated with islands. Backwater habitats are not typically used for barge navigation and occur between an island and the mainland. Seven backwater areas (associated with seven islands) occur within the Belleville Pool. Habitats near the upstream and downstream ends of each island are island head and island tail habitats, respectively. Embayment habitats are shallow bay-like areas connected to the main channel by tributary or artificial channel. Wing dams (and other artificial flow barriers) create near-shore habitats with low water velocities.

Selection and description of study sites

Initially, we selected six main channel sites, six tributary confluences, six backwater areas, six head of islands, six tail of islands, and three deep hole sites (Figure 3-1; see coordinates in Table 3-2). Main channel and tributary sites were selected randomly within Belleville Pool and stratified relative to their abundance in the upper and lower half. We added two main channel sites, three tributary sites, three deep hole sites, one wing dam (artificial) site, and an embayment (Figure 3-1; Table 3-2). Depths of main channel and backwater sites ranged from 3 to 9 m, and included near-shore mid-channel transects. Tributary habitats were 2 to 9 m deep, and included near-shore areas and deeper scour holes. Depths of deep hole habitats ranged from 7 to 14 m, and those of island head and tail habitats ranged from 2 to 6 m. Island size differed among Newberry (0.4 km long), Blennerhasset (6.4 km long), Neal (2.4 km long), Halfway (1.6 km long), Muskingum (3.2 km long) and Marietta (4.8 km long), but sample areas within backwater, head, and tail habitats were similar among islands. Depths, flows, and water quality of each habitat type are presented with results.

Sampling methodology

Abiotic data

At each sample site, we used a YSI 6820 meter or a Hydrolab Surveyor 4 to measure specific conductivity, dissolved oxygen (DO), pH, salinity, and temperature depth profiles at 1m intervals. Turbidity was estimated with secchi disk (near surface), and a YSI 6820 meter along 1 m depth profiles during the December 2002 and January 2003 sample sessions. We measured flow velocity with a Marsh-McBirney Flowmate 2000 at the surface (depths < 1.5 m) or at 2 m.

Bottom contour and depth profiles for each transect at each site were recorded by sonar during peddle time. Tidbit dataloggers recorded water temperatures every 30 minutes at three main-channel (RM180, RM196, and near head of Marietta Island) and three back-channel (Blennerhasset, Newberry, and Neal Islands) sites during February 2002 through March 2003. Presence/absence of large woody debris was recorded for each site.

Fish sampling

Fishes were sampled with a variable-depth AC electrofishing boat for depths of 2-10 meters (Grunwald 1983, Newcomb 1989). Our boat is an 18 ft flat-bottom (7 ft wide) aluminum jon boat with a 5 kilowatt Honda 3-phase AC generator. Three electrodes (2 m sections of 1.25 inch diameter corrugated conduit) are attached to 14-gauge 3-strand pre-insulated solid wire. The wire from the three electrodes connects to an electrical junction box, which is wired to the generator. A ground wire connects the boat and generator. Amp output is turned off by the generator's on/off switch or by a safety footswitch (controlled by the boat operator). If needed, we reduce amp output by taping the electrodes, i.e., amps decrease when the electrode surface is covered with electrical tape.

The amp output is monitored by inline amp gauges and/or clip-on amp gauges. Output is generally above 7 amps, and typically 9-10 amps.

Electrodes were weighted and lowered to the river bottom off a boom on the bow. We attempted to get the electrodes near bottom without making contact. One, two, or three transects were electrofished in the direction of the river current lasting up to10-minutes (peddle time) for each sampling location. During peddle time with the bow upstream, we allowed the boat to drift with the river current. This maintained electrodes near the river bottom, but caused longer transects during higher flows. In backwater and main channel habitats, the three transects represented shallow, intermediate, and deep water areas and were sampled near each shore and in mid-channel. Peddle time and number of transects varied with habitat availability. Often, we sampled two transects within the small areas of island head and island tail habitats, or one transect within scour holes of tributary habitats. During or after peddle time, researchers in a chase boat or the electrofishing boat netted fishes from the water surface.

Fish data

Fishes were captured, identified to species, measured (nearest millimeter total length, TL), and weighed. Weights for large fishes (over 1kg) were taken to the nearest 25g with a Pesola spring scale (5 kg maximum). Smaller fishes (less than 1 kg) were weighed to the nearest 1g with a Homs spring dial scale (1kg maximum). Channel catfish, black crappie, white crappie (*Pomoxis annularis*), hybrid striped bass (*Morone saxatilis x Morone chrysops*) and freshwater drum were weighed and frozen for removal of spines or otoliths. Ages of channel catfish were determined with sections of pectoral

spines, whereas ages of other species were based on otoliths. We used at least two observers for age estimation.

Data management procedures

We archived copies of field notes, lab data, and electronic data files and recorded metadata for electronic data files. Data, stored primarily in Excel spreadsheets, were checked for accuracy after transfer from field notes.

Statistical methods

Site occupancy rates

Abundance or presence/absence estimates are often biased (underestimated) unless adjusted with detection probabilities (MacKenzie and Kendall 2002). We used occupancy rate models (a method that incorporates detection probabilities) to estimate the proportion of sites occupied by freshwater drum and channel catfish using presence/absence data (MacKenzie et al. 2002). Specifically, we used Program MARK to estimate maximum likelihoods of two parameters: the probability of detection (p) and the proportion of sites occupied by a species (ψ). The proportion of sites occupied by a species could be estimated as the fraction of sites with species detections over the total number of sites. For example, if freshwater drum were collected in 10 of 20 tributary habitats, then one estimate of ψ is 10/20 or 0.5. This estimate, however, is biased (low) if the probability of detection is less than 1 (nondetection may not equal absence). Detection probabilities can be estimated with data from multiple visits to each site, and used to adjust ψ. If a species was detected on the second sample occasion, but not on the

first and third occasions, then the likelihood of ψ given detection probabilities (p) for site *i* would be as follows:

$$L(\psi, p) = \psi_i (1 - p_{i1}) p_{i2} (1 - p_{i3})$$

The likelihood for a capture history of three occasions without detection at site k would be as follows:

$$L(\psi, p) = \psi_k \prod_{t=1}^{3} (1 - p_{kt}) + (1 - \psi_k)$$

Selection of occupancy rate models followed an information-theoretic approach based on Kullback-Leibler information and likelihood theory (Burnham and Anderson 1998). A set of candidate models for estimates of p and ψ were selected before analysis. Biologically-reasonable hypotheses were used to develop the set of candidate models and were examined under a multiple working hypotheses framework (Chamberlin 1965). We modeled parameter ψ as unique for each habitat type or constant across habitat types, with notation as ψ(habitat) and ψ(.), respectively. Detection probabilities were modeled as (1) unique for each site, (2) constant across sites, (3) with time as a covariate, or (4) with abiotic covariates of conductivity, depth, DO, temperature, or velocity. Additional models with interaction terms were not considered given our sparse (many zeros) data set.

Candidate models were fit to the data using Program MARK, and selected based on a second order adjustment to Akaike's information criterion (AICc; Burnham and Anderson 1998), where

$\mathrm{AIC_c} = -2\log\left(L(\hat{\theta})\right) + 2K + \frac{2\mathrm{K}(\mathrm{K}+1)}{(\mathrm{n}-\mathrm{K}-1)}$, and n = sample size, K = number of model parameters. The model likelihoods were determined by comparing Akaike model

weights (as described below). The AICc values were rescaled as simple differences, where $\Delta_i = AIC_{ci} - \min AIC_c$. Then the likelihood of model *i*, given the data, is $L(M_i|\underline{x}) = \exp(-\frac{1}{2}\Delta_i)$, and normalized to sum to 1, as $w_i = \frac{\exp(-\frac{1}{2}\Delta_i)}{\sum_{r=1}^{R}\exp(-\frac{1}{2}\Delta_i)}$. The w_i values can be interpreted as probabilities, where the relative likelihood of model i versus model j is w_i/w_j. For example, given weights of 0.9 for model i and 0.1 for model j, then the model i is nine times more likely than model j.

We estimated p and ψ as a weighted average across all models, where weight is a function of model fit (Burnham and Anderson 1998; Buckland et al. 1997). Model averaging eliminates the need to select the single best model, allowing the uncertainty of model selection to be incorporated into the variance of parameter estimates (Burnham and Anderson 1998).

Multivariate descriptive and exploratory analysis

Following occupancy rate estimation, we used canonical correspondence analysis (CCA) to explore relationships between species and abiotic variables. Canonical correspondence analysis is a constrained ordination approach, and allows concurrent analysis of species abundance, site, and environmental (abiotic) data (ter Braak 1995). A square root transformation of abundance data minimized affects of a few high abundance values (McGarigal et al. 2000). We conducted CCAs using an Excel macro with data from February - April 2002 and December 2002 – March 2003, separately (macro obtained from Eric Smith, Virginia Polytechnic Institute and State University).

Sampling efficiency

Sampling efficiency, the percent of the population captured by sampling, is important in studies of animal abundance. Poor sampling efficiency will provide low (biased) estimates of abundance. Sampling efficiency of a gear type is difficult to quantify, but can be examined by sampling with other gears or toxicants. Few gears, however, provide 100% detection probabilities for all individuals or all species within open systems, such as macrohabitats of large rivers. Researchers at Southern Illinois University (SIU, Garvey et al. 2002, Chapter 2) conducted a companion study on winter habitat used by fishes in Smithland Pool, and we compared sampling efficiencies of the SIU and WVU boats. Additionally, we compared sonar, gill nets, DC electrofishing, and multiple pass removals with data collected by AC gear.

We attempted to corroborate abundance data from February 2002 – March 2003 with concurrent electrofishing and sonar surveys. We used sonar images to estimate fish abundance prior to electrofishing and to assess gear efficiency. A stern-mounted sonar device recorded fish abundance along with bottom contour profiles of each transect. Electrofishing was conducted by moving the boat backward, and the recorded sonar image was captured immediately preceding the passage of the bow-mounted electrofishing electrodes.

We used experimental gill nets at 11 sites and a Smith-Root DC electrofishing boat at one site for comparison with the variable-depth AC electrofishing boat. Gill nets were five panels (8 by 32 feet) with 3 to 12 inch stretched mesh. Anchored gill nets (a passive method) will likely be unsuccessful at capturing inactive fishes during winter. The use of gill nets will not provide an estimate of our electrofishing gear efficiency, but it may indicate species-specific vulnerabilities to gear types. For example, species

captured with gill nets and not with electrofishing would support gear-specific differences. Comparing abundance data collected by DC electrofishing (with electrical field near the water surface) and variable-depth AC electrofishing boat (with electrical field near river bottom) also has limitations, and is restricted to relatively shallow habitats. In December 2002, we compared DC and AC electrofishing boats at the Blennerhasset Island tail.

We conducted multiple-pass removal samples at Bull Creek (January 2003 and March 2003) and main channel RM 165 (March 2003). We examined the relationship between fish size and estimates of detection probabilities. Although fishes were free to move in and out of the sample area, we believe low water temperatures and short time periods (approximately 10 minutes) between electrofishing passes minimized fish movements. Detection probabilities were estimated using the closed capture option in Program MARK, where four models were fit to the three-pass removal data. Among-species differences in detection probabilities were not important to our analysis, so we combined species to increase sample size, and separated fishes into two size groups (<300mm, >300mm). Standard removal models (Otis et al. 1978; White et al. 1982), and models reflecting fish size were selected with AIC and information theoretic methods as described above. Detection probabilities from the three-pass sample were parameterized as (1) equal among sample occasions and between size groups, (2) equal among sample occasions with unequal size groups, (3) equal for second and third sample occasions with equal size groups, and (4) equal for second and third sample occasions with unequal size groups. Analyses of two-pass samples were restricted to the first two models (listed above).

RESULTS

Effort and Sample dates

First sample phase (February, March, and April of 2002)

Thirty-seven sites were sampled during February, March, and April of 2002, including nine tributary confluences, six backwater areas, six head of islands, six tail of islands, seven main channel sites, and three deep main channel sites (Table 3-2). Sites were sampled from one to four times across four sample sessions (session 1, February 16 – 22; session 2, March 9 – 25; session 3, April 4 – 7; session 4, April 14 - 15). Based on higher temperatures, session 4 was not representative of winter conditions.

Second sample phase (December 2002, January 2003, March 2003)

During December 2002, January 2003, and March 2003, we sampled six tributary confluences, six backwater areas, six head of islands, six tail of islands, six main channel sites, and six deep main channel sites (Table 3-2). Sites were sampled from one to three times across the three sample sessions (session 1, December 12-17; session 2, January 10 – 19; session 3, March 1 – 17). Samples during March were interrupted by high flows and occurred during March 1 – 2 and March 16 – 17). We added a shallow embayment site (Little Sand Creek) in December 2002, and a wing dam, main channel, and deep hole sites in January 2003 (Table 3-2). Mean depths of sample transects (estimated with 50 randomly-selected depth measurements) were lowest for head and tail island habitats and highest for deep hole habitats (Table 3-3).

Abiotic data

Abiotic data are summarized in Table 3-4. Water temperatures (Celsius) ranged

from 4.4 to 5.5, 5.5 to 7.7, 8.7 to 11.2, and 11.5 to 15.2 during our first, second, third, and fourth sampling sessions of 2002, and from 1.9 to 5.1 in December 2002, 0.4 to 3.6 in January 2003, and 1.95 to 11.24 in March 2003. The high temperature in March (11.24 C) was from the embayment habitat, whereas all other habitats had water temperatures below 6.4 C. Temperatures measured along 1 m depth profiles differed typically less than one degree Celsius (see Welsh et al. 2003 for specific profiles). Tidbit dataloggers recorded similar water temperatures among three main-channel and three back-channel sites during February 2002 through March 2003 (Table 3-5; Figure 3-2, 3-3). Turbidity ranged from 2.4 to 214 (NTU) in December 2002, 1.2 to 75.1 in January 2003, and 17.9 to 119.9 in March 2003, whereas secchi disk readings ranged from 0.15 to 2.15 m in December 2002, 0.33 to 1.6 m in January 2003, and 0.16 to 0.78 in March 2003. Turbidity and secchi readings were not taken during the February – April 2002 sample sessions because of equipment failure and oversight. Dissolved oxygen (mg/L) ranged from 13 to 13.9, 7.3 to 9.3, 6.6 to 12.5, and 9.9 to 12.3 during our first, second, third, and fourth sampling sessions in 2002. Dissolved oxygen ranged from 6.5 to 9.5 in December 2002, 12.1 to 14.6 in January 2003, and 11.07 to 13.79 in March 2003. Specific conductivity (uS/cm) ranged from 285 to 496, 244 to 408, 89 to 434, and 136 to 597 during the first, second, third, and fourth sampling sessions of 2002, and from 153 to 570 in December 2002, 321 to 520 in January 2003, and 185 to 545 in March 2003.

Flow velocity (m/s) at the surface (depths < 1.5 meters) or at 2 meters depth ranged from 0.04 to 0.38, 0 to 1.0, 0 to 1.1, and 0 to 1.15 during our first, second, third, and fourth sampling sessions of 2002, and from 0.0 to 1.0 in December 2002, 0.0 to 0.84 in January 2003, and 0 to 1.25 in March 2003. River stages at Marietta depict high flows during our sample periods (Figure 3-4). Instream structures (i.e. logs near water surface)

were present within sampling transects of tributaries (Lee Creek, Little Hocking River), backwaters (Halfway, Marietta, Neal, Newberry), Island heads (Marietta, Newberry), Island tails (Blennerhasset, Marietta, Muskingum), and main channels (river miles 165, 180, 192, 194).

Fish habitat use

Species composition (both years)

We sampled 515 transects and captured 28 species with a variable-depth AC electrofisher during February 2002 through March 2003 (Table 3-6). Relative numbers of common species were similar to those from previous lock rotenone samples between RM 100 – 200 (Pearson and Krumholz 1984); freshwater drum and channel catfish were most abundant. Seventeen species were captured with a DC electrofisher from Little Sand Creek embayment. Thirty-two species were captured (based on all gears) during February 2002 through March 2003.

Species composition by habitat type and sample event

During the first phase (February – April 2002), we sampled 248 transects and captured 15 species (Table 3-7; see Welsh et al. for specific catch data). No fishes were detected at 194 transects. Channel catfish, freshwater drum, and gizzard shad were most abundant. We captured 119 channel catfish during February – April 2002, and percentages by habitat type were as follows: 63% tributary, 14% backwater, 5% island head, 2% island tail, 16% main channel, and 0% deep hole. Percentages of freshwater drum (N=174) by habitat type were as follows: 90% tributary, 2% backwater, 2% island head, 0% island tail, 6% main channel, and 0% deep hole. Tributary habitats had highest

species abundances and the highest species richness, including gizzard shad, mooneye (*Hiodon tergisus*), common carp (*Cyprinus carpio*), emerald shiner (*Notropis atherinoides*), spottail shiner (*Notropis hudsonius*), highfin carpsucker (*Carpiodes velifer*), river carpsucker (*Carpiodes carpio*), quillback (*Carpiodes cyprinus*), channel catfish, orangespotted sunfish (*Lepomis humilis*), bluegill, white bass (*Morone chrysops*), walleye, and freshwater drum. The number of fishes collected in tributary confluences made up 83% of all individuals collected. No fishes were collected from the three deep hole sites.

During the second sample phase, fishes were not detected with variable-depth AC sampling at 71 of 88 transects in December 2002, 68 of 88 transects in January 2003, and 58 of 91 transects in March 2003. Although this seems to be a high rate of nondetection or species absence, it is consistent with samples from early 2002. Total species captured was similar between sample phases with 15 species captured in early 2002 and 23 species captured during December 2002-March 2003. Species presence in backwater and main channel habitats during December 2002 through March 2003 exceeded that from early 2002 samples. In an embayment habitat (Little Sand Creek, December 2002 through March 2003), we sampled 17 species (890 individuals) from two near-shore transects with a Smith-Root DC electrofishing boat. This included nine species not captured with our AC gear during December 2002 – March 2003 (bowfin, *Amia calva*; spotted sucker, *Minytrema melanops*; western mosquitofish, *Gambusia affinis*; white crappie; green sunfish; pumpkinseed, *Lepomis gibbosus;* warmouth, *Lepomis gulosus*; orangespotted sunfish; and bluegill). With these species, a total of 32 species was sampled during December 2002 through March 2003. The two near-shore transects in the embayment were shallow (< 1 m depth) with LWD, and could not be sampled with our variable-depth

AC electrofishing boat. We sampled one transect in the embayment (away from shore with 2 m depth) with the variable-depth AC electrofishing boat and captured one freshwater drum.

We captured 83 channel catfish during December 2002 through March 2003, and percentages by habitat type were 16% (tributary), 31% (backwater), 0% (island head), 0% (island tail), 52% (main channel), and 1% (deep hole). Percentages of freshwater drum (N=296) by habitat type were 37% (tributary), 7% (backwater), 0% (island head), 0.3% (island tail), 50% (main channel), 1% (deep hole), 2% (embayment), and 2% (wing dam). The highest species richness (N = 11) was taken from the embayment habitat in December 2002. Tributary habitats contained the highest species richness (N=13) in January 2003. Most species of tributary habitats in January came from one site, Bull Creek, whereas the embayment habitat was not sampled in January due to ice-cover. During March 2003, 16 and 10 species were sampled from embayment and tributary habitats, respectively. Although no species were collected from deep hole sites during February – April 2002, we captured three species (channel catfish, spotted bass, and freshwater drum) from a deep hole site near Marietta Island in December 2002.

Species composition by gear type

The primary gear was variable-depth AC electrofishing (515 transects; 28 species), whereas DC electrofishing (9 transects) and gillnets (11 sets) were used infrequently. Results from DC electrofishing at the Blennerhasset Island tail (December 2002) and gill nets (11 sites) were compared to variable-depth AC gear (summarized below), whereas DC electrofishing in the embayment was used to sample a unique habitat

(nearshore embayment; inaccessible to the AC gear). We fished the Little Sand Creek embayment three times (during December 2002 and March 2003) with the DC electrofishing boat and captured 17 species. Nine of these species were not captured with AC gear during December through March 2003.

Size distribution, length-weight comparison, and ages

Size distributions of abundant species were depicted for both field seasons (combined and separate; Figures 3-5 through 3-7). The range of lengths and presence of multiple length frequency modes indicate several year classes within samples. However, we captured primarily adults (except for Little Sand Creek embayment), but juvenile freshwater drum were captured in tributary, backwater, main channel, and embayment habitats. In general, size distributions by gear, month, or habitat were inhibited by small sample sizes. Data from the embayment habitat (DC gear), however, are presented separately for orangespotted sunfish, bluegill, and white crappie (Figure 3-8; see Appendix 1, Lenz 2003).

Age-length relationships were examined for channel catfish, white bass, white crappie, and freshwater drum (Figures 3-9 through 3-12). Lenz (2003) reported von Bertalanffy growth models of channel catfish, white bass, and freshwater drum (Appendix 1). Mean lengths (variances and sample sizes in parentheses) of white crappie (ages 1 through 4) were 7.6 (1.08, 18), 13.8 (2.44, 25), 19.4 (5.28, 9), 28.4 (1.6, 10) cm, respectively. Mean lengths of white bass (ages 1 through 4) were 11.2 (NA, 1), 18.8 (3.36, 16), 27.8 (0.84, 10), 30.4 (1.3, 5) cm, respectively. Mean lengths (cm) of channel catfish (ages 0 through 9) were as follows: 12.4 (NA, 1), 23.8 (9.7, 5), 24.8 (39.7, 11), 35.6 (19.4, 48), 38.4 (40.7, 13), 45.6 (37.8, 23), 50.5 (55.5, 6), 54 (6.0, 6), 53 (NA, 1), 62

(32.0, 2). The oldest freshwater drum was estimated at 22 years (77 cm TL); ages 0 to 14 had mean lengths of 5.5 (0.5, 2), 8 (1.61, 60), 17.3 (8.2, 40), 23.8 (2.5, 50), 28.6 (5.59, 47), 31.6 (5.43, 20), 37.9 (8.1, 12), 45.0 (27.6, 6), 44.8 (63.6, 5), 48.7 (5.9, 8), 49 (32.0, 2), 48 (36.0, 5), 54.7 (21.2, 7), 58.7 (37.3, 3), 61.0 (8.0, 2). High variances, in part, reflect uncertainty from small sample sizes.

Relative abundance (CPUE)

With data combined for February 2002 through March 2003, CPUE (fish/hour) was highest for gizzard shad (10.6), freshwater drum (9.9), channel catfish (4.2), bluegill (3.4), emerald shiner (3.0), white crappie (1.5), smallmouth buffalo (1.4), orangespotted sunfish (1.0), and white bass (0.96) (Tables 3-8, 3-9, 3-10). The CPUE estimates for gizzard shad, emerald shiner, white crappie, and sunfish were largely influenced by catches within the Little Sand Creek embayment. The estimates for smallmouth buffalo and white bass were influenced by a single sample at a wing dam.

When separated by habitat types and sample events (excluding the embayment), CPUE was generally highest for tributaries (see Tables 26-34 in Welsh et al. 2003). During December 2002 and January 2003, however, CPUE for channel catfish and freshwater drum (the two species with highest abundances) increased in backwater and main channel habitats. A single sample from a wing dam habitat provided highest CPUE (fish/hour) estimates for carp (5.2), black buffalo (5.2), smallmouth buffalo (90.0), white bass (5.2), and freshwater drum (52.6).

Results of occupancy rate modeling

Site occupancy rate models were used to estimate detection probabilities (p) and the proportion of sites occupied (ψ) by freshwater drum in tributary, backwater, and main channel habitats. Models with depth, flow, and constant detection probabilities received highest weights for freshwater drum (Table 3-11). Model-averaged estimates of ψ were highest for tributaries during February through early April 2002, but were highest for main channel habitats during December 2002 through March 2003 (Table 3-12). Habitat specific parameters for ψ were unestimable for other species because of sparse data.

Results of multivariate exploratory analysis

Relationships among species abundances and environmental variables (flow, temperature, conductivity, depth, and turbidity) were depicted in CCA triplots (Figures 3-13, 3-14). For data from February 2002 through April 2002, the relationship among low flows, tributaries, and abundance of freshwater drum were emphasized along the axis of flow. To a lesser extent, channel catfish were also associated with areas of low flow velocities. Similarly, flow was the major axis and tributary habitats were associated with low flows from December 2002 through March 2003; flow, temperature, and conductivity depicted similar gradients. Higher flows, temperatures, and conductivities in main channel and backwater areas, however, were associated with the two species of highest abundance (freshwater drum and channel catfish) during December 2002 through March 2003. No relationship occurred among species, habitat types, and turbidity. Depth was associated with deep hole habitats, but not with species.

Sample efficiency

Sonar images were used to assess gear efficiency by comparison of the number of fishes viewed by sonar and the number of fishes collected at each site. We did not find a relationship between the number of fishes viewed by sonar and the number of fishes collected at each site during both seasons. During the 2002 season, the two methods were consistent during 91 transect samples, where no fishes were viewed on sonar and no fishes were collected (this includes the three deep main channel sites). Also, the number of fishes viewed on sonar equaled the number of fishes collected during six transects. However, 44 transects had a higher number of fishes viewed on sonar than collected, whereas the number of fishes collected exceeded the number of fishes viewed on sonar at 28 sample locations. Similarly, during the 2003 season, the two methods were consistent (no fishes collected or viewed) during 125 transect samples. The number of fishes viewed on sonar equaled the number of fishes collected during seven transects. Forty-three transects had a higher number of fishes viewed than collected, whereas the number of fishes collected exceeded the number of fishes viewed at 34 sample locations.

Other methods to assess sampling efficiency included comparison of the WVU variable-depth AC electrofishing boat with (1) a similar boat used by SIU, (2) a Smith-Root DC electrofishing boat, and (3) anchored gillnets. The variable-depth AC electrofishing boats of SIU and WVU are similar in construction and sampled with similar efficiency during comparison. Eleven gill nets were fished during the December 2002 through March 2003 sample sessions (Table 3-13). Three gill nets were set overnight at Bull Creek (tributary habitat), Marietta Island head, and river mile 167 (main channel) in December and were fished for a combined total of 76.85 hours. In January, three gill nets

were fished during the daytime at Neal Island head, tail, and backwater sites for a combined total of 14 hours. During March 2003, three gill nets were fished (Lee Creek, Hocking River, and Newberry Island tail) for 16.75 hours, collectively. Seven of the 11 gill net sets caught no fish, yielding the same results as the AC electrofishing efforts. The gill net at Bull Creek caught three fishes (two sauger and a shorthead redhorse) and none were captured with AC gear. At Neal Island backwater, the AC gear produced four fishes (three channel catfish and a freshwater drum) and the gill net caught one (a mooneye). In March, two carp were captured with a gill net at Lee Creek, whereas six freshwater drum and one gizzard shad were captured with AC gear.

In December 2002, DC and AC electrofishing boats were compared at the Blennerhasset Island tail and the embayment. We captured four fishes (a freshwater drum, two mooneye, and a sauger) from three transects sampled with the variable-depth AC electrofishing boat at the Blennerhasset Island tail in December 2002. We repeated the transects with a Smith-Root DC electrofishing boat and captured a silver chub (*Macrhybopsis storeriana*) and a smallmouth buffalo.

A three-pass removal sample at Bull Creek during January 2003 provided another look at sampling efficiency for the variable-depth AC gear. We captured 57, 6, and 1 fishes over 300 mm TL during three passes, respectively. Fishes under 300 mm TL from the three passes were 39, 31, and 1, respectively. The best approximating model parameterized detection probabilities as equal for second and third sample occasions with unequal size groups. The detection probability (with SE and 95% CI in parentheses) of small fishes (< 300 mm TL) for the first pass was 0.55 (0.06, 0.43 to 0.66), whereas the combined estimate for the second and third passes was 0.97 (0.03, 0.81 to 1.0). Detection probabilities of large fishes (> 300 mm TL) for the first and subsequent passes

were 0.89 (0.04, 0.79 to 0.95) and 0.88 (0.12, 0.46 to 0.98), respectively. Two-pass removals at Bull Creek (March 2003) and main channel RM 165 (March 2003) yielded 28 and 4, and 34 and 11 individuals, respectively. We were unable to model data from Bull Creek (March 2003) due to small sample size; however, detection probability for fishes >300 mm TL ($p = 0.85$, 95%CI = 0.62 to 0.95) exceeded that for smaller fishes ($p = 0.69$, 95%CI = 0.36 to 0.88) from the best approximating model for RM 165.

DISCUSSION

Species/habitat associations

Canonical correspondence analysis and abundance estimates depicted low-velocity tributary habitats with highest abundances and richness of fishes during our February 2002 through March 2003 sample sessions. The proportion of tributary sites occupied by species was consistently higher than that of Island head, Island tail, and deep hole habitats. We believe that fishes used tributary habitats because of low velocities. Average surface velocity (m/s) for tributary confluences (0.10) was lower than those of backwater (0.58), island head (0.57), island tail (0.30), main channel (0.56), and deep hole (0.65) habitats. Carlson (1992) and Braaten and Guy (1999) also reported low-velocity tributary confluences as important winter refuges. During the December 2002 sample, water temperatures were consistently between 3 and 5 °C for all habitats. In January 2003, all tributary habitats were below 3 °C, except for Bull Creek (3.2 °C) and Sugar Camp Run (3.2 °C) which had highest estimates of abundance and richness. Although other unmeasured variables may explain fish use of tributary habitats during winter, we believe that low velocities are important, except when water temperatures fall below 3 °C.

Backwater and main channel habitats were similar in many physiochemical measurements, including flow velocity, temperature, and depth. In some large rivers, backwater areas have warmer water temperatures and provide a shelter from current velocity during winter (Bodensteiner and Lewis 1992, Johnson et al. 1998, Raibley et al. 1997, Sheehan and Rasmussen 1999). The backwaters in the upper Ohio River valley are not characteristic of other large river backwaters that are slow-moving isolated sloughs. Our sample efforts did not find high abundance or diverse fish assemblages in backwater and main channel habitats, except when water temperatures in low-velocity tributary habitats were below 4 °C. Our data indicate that many large river fishes trade low-velocity habitats for relatively high-velocity areas when water temperatures of low-velocity areas drop below 4 °C. During our coldest sampling events (December 2002 and January 2003), the abundances of several species increased in backwater or main channel habitats, such as gizzard shad, mooneye, carp, smallmouth buffalo, channel catfish, and freshwater drum (as supported by occupancy rate models). Fishes in backwater and main channel habitats were primarily captured in near-shore transects, and taken rarely from mid-channel transects. Consequently, estimates of occupancy rates in island backwaters and main channels were decreased by low catches in mid-channel transects.

Few embayments occur within Belleville Pool, but our data from Little Sand Creek embayment support their importance as winter refuge habitats. We captured high abundances of juvenile sunfish (bluegill, green, orangespotted, pumpkinseed, and warmouth), juvenile white crappie, and juvenile gizzard shad in the low-velocity embayment habitat. Additionally, three juvenile freshwater drum were captured in the embayment habitat. Within other habitats, we captured mostly adult fishes (possibly from size selectivity of electrofishing gear). Juvenile fishes suffer higher mortality than

adults at critically low water temperatures (Post et al. 1998, Wright et al. 1999, Fullerton et al. 2000, Jackson and Noble 2000, Bodensteiner and Lewis 1994); consequently, our sampling gear (if selectivity is an issue) missed an important component of winter fish/habitat relations, i.e., winter habitats of juvenile fishes. Our finding of juvenile fishes in a low-velocity habitat is consistent with other literature (Bodensteiner and Lewis 1992, Braaten and Guy 1999); however, we did capture juvenile freshwater drum in relatively high-velocity backwater and main channel habitats.

Dissolved oxygen, conductivity, and turbidity were not associated with differential habitat use among habitat types. Although dissolved oxygen concentrations may decline in some backwater areas during winter (Gent et al. 1995, Knights et al. 1995), data herein and those from Pearson and Krumholz (1984) indicate that DO remains relatively high in Belleville Pool. It is unlikely that DO influenced fish presence during our study, given similar and high DO values among habitat types and sample events. Similarly, the range of conductivity during our sample periods did not likely influence fish presence. Conductivity, however, is known to affect electrofishing efficiency, and its importance to estimates of detection probabilities of freshwater drum is discussed under sampling efficiency. Analyses did not support turbidity (based on secchi and NTU measurements) as an influence on habitats used by fishes.

Sample efficiency and gear selectivity

Our efforts with variable-depth AC electrofishing produced primarily freshwater drum and channel catfish. In a companion study in the lower Ohio River (Smithland Pool) during winter 2001/2002, the catch was predominantly blue catfish (*Ictalurus furcatus*) and freshwater drum (Garvey et al. 2002; Chapter 2). Sheehan et al. (1990)

used variable-depth AC electrofishing gear to capture a diversity of species, and Newcomb (1989) predominantly captured channel catfish, common carp, freshwater drum, river carpsucker, and goldeye (*Hiodon alosoides*) using variable depth AC electrofishing gear. Deepwater electrofishing gear targets fish species on or near the river bottom, and this likely explains the relatively high numbers of catfish and freshwater drum; however, we did capture 28 species with our AC gear.

A comparison of our sonar images with the number of fishes collected indicated that the gear was often inefficient at capturing all fishes (when fishes were present); however, this is probably true for most gear types. The sonar method has limitations, in part, because sample area of sonar (with 36 degree cone) differs with water depth, and rarely equals the sample area of the electrofisher. Also, interpreters of sonar graphs can overlook fishes near the river bottom or count images of logs or other objects. Data from gill nets and DC electrofishing did not support poor sampling efficiency of the variable-depth AC electrofishing boat. However, this type of gear comparison has limitations, given that gill nets and DC electrofishing may have poor sampling efficiency. Sampling efficiency for the DC electrofishing boat was high at near-shore areas within the embayment habitat; however, the AC electrofishing gear could not access this near-shore shallow habitat. Possibly, shallow near-shore areas within the six habitat types provide important over-winter habitats, but were not sampled during our study.

Estimates of detection probabilities may be useful in assessing sample efficiency. Detection probabilities in site occupancy models, however, are defined as the probability that a species is detected, and not as the probability that a gear type detects a species. However, conductivity and flow models of detection probabilities received low weights; hence, the data did not support an association with sampling efficiency, conductivity, and

water velocity.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Based on data from six habitats (backwater, island head, island tail, main channel, and tributary), fishes primarily used low-velocity habitats at tributary mouths during winter conditions. Consequently, the importance of habitats at tributary confluences should be emphasized within management plans. Some species, however, used areas with higher velocities and relatively warmer temperatures during periods when low-velocity tributary habitats were below 4 °C. Embayment and wing dam habitats had relatively high abundances and species richness, but were underrepresented in our study (because of inaccessibility or unavailability). Although one embayment and one wing dam were evaluated during our study, we believe that these habitats are important winter refuges, and if possible, should be emphasized in management and future studies on winter habitats used by fishes in the Ohio River. Additionally, future studies during winter should evaluate near-shore areas of all habitat types, which may provide insights into habitats used by juvenile fishes. Additionally, studies need to address impacts of habitat disturbances on fish survival during winter, including high flow events and barge traffic.

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Table 3-1. Description of macrohabitats within Belleville Pool, Ohio River.

Habitat type	Description
Main Channel	Area extending from shore including the center of the channel.
Backwater	Area between an island and the shore without barge traffic.
Island head	Area adjacent to the upstream end of an island.
Island tail	Area adjacent to the downstream end of an island.
Tributary	Area encompassing a tributary mouth and its connection to the main channel.
Embayment	A shallow bay-like area connected to the main channel.
Artificial wing dam	A near-shore area of low velocity created by an artificial barrier.
Deep hole	Dredged or natural scour areas within the main channel or back channel.

Table 3-2. Site locations and sample dates of habitat types within Belleville Pool, Ohio River.

			Month/Date					
Site, by habitat type	Latitude	Longitude	2002 Feb	2002 Mar	2002 Apr	2002 Dec	2003 Jan	2003 Mar
Tributary								
1) Bull Cr.	39.20.19.5	81.22.13.8		25	6, 15	12	11	2
2) Duck Cr.	39.24.17.8	81.25.38.1		9, 24	6, 15	12	11	2
3) Lee Cr.	39.09.00.5	81.44.28.5	16, 22		4, 7	15	18	1
4) Little Hocking R.	39.15.46.7	81.41.38.5	17		5, 7	16	13	17
5) Little Kanawha R.	39.15.51.1	81.34.04.9		15	5, 14	16	19	16
6) Hocking R.	39.11.02.9	81.45.15.6	16, 22		4, 7	15	18	1
Backwater								
1) Blennerhasset	39.16.14.1	81.38.45.3		14	5, 14	16	19	17
2) Halfway	39.21.11.8	81.32.46.6		24	6, 15	17	10	16
3) Neal	39.18.29.9	81.33.19.8		15	6, 14	17	10	16
4) Newberry	39.13.12.4	81.41.32.0	17		5, 7	15	18	1
5) Marietta	39.23.41.6	81.25.18.4		25	6, 15	13	12	2
6) Muskingum	39.21.44.7	81.30.37.4		24	6, 15	17	19	16
Island head/tail								
1) Blennerhasset head	39.16.10.2	81.35.40.9		14	5, 14	16	19	17
2) Blennerhasset tail	39.16.29.3	81.39.38.0		14	5, 14	16	19	17
3) Halfway head	39.21.23.6	81.32.20.3		24	6, 15	17	10	16
4) Halfway tail	39.20.55.0	81.32.59.5		24	6, 15	17	10	16
5) Neal head	39.18.51.1	81.33.31.9		15	6, 14	17	10	16
6) Neal tail	39.17.43.7	81.33.44.5		24	5, 14	17	10	16
7) Newberry head	39.13.16.7	81.41.32.8	17		5, 7	16	18	1
8) Newberry tail	39.13.13.0	81.41.41.2	17	11	5, 7	15	18	1
9) Marietta head	39.23.03.8	81.24.30.6			6, 15	12	12	2
10) Marietta tail	39.24.31.2	81.26.48.3		9, 25	6, 15	12	12	2
11) Muskingum head	39.22.36.5	81.29.36.3		24	6, 15	17	19	16
12) Muskingum tail	39.21.34.3	81.31.25.3		24	6, 15	13	10	16
Main Channel								
1) River Mile 165	39.20.23.8	81.22.12.7		25	6, 15	12	12	2
2) River Mile 167	39.21.51.0	81.23.54.4		25	6, 15	12	12	2
3) River Mile 180	39.20.07.0	81.33.18.3		24	6.15	17	10	16
4) River Mile 184	39.16.31.2	81.33.56.6		24	6, 14	17	19	16
5) River Mile 192	39.15.38.3	81.41.29.1		14	5, 7	16	13	17
6) River Mile 194	39.13.38.4	81.41.21.0		14	5, 7	16	18	1
Deep Hole								
1) River Mile 170 #1	39.23.38.2	81.25.08.3		25	6,15	13	11	2
2) River Mile 170 #2	39.23.42.9	81.25.15.3				13	11	2
2) River Mile 180	39.19.56.6	81.33.27.7		24	6,15	17	10	16
3) River Mile 198	39.11.13.9	81.44.34.4	22	14	7	15	18	1

Table 3-2. Continued.

			Month/Date					
	Latitude	Longitude	2002 Feb	2002 Mar	2002 Apr	2002 Dec	2003 Jan	2003 Mar
Extra								
1) Moore's Run	39.22.40.4	81.29.51.4		24				
2) Williams 2-Mile Cr.	39.23.15.0	81.28.46.8		24				
3) Sugarcamp Run	39.21.39.0	81.24.06.0		24			11	
4) River Mile 176	39.21.45.0	81.31.11.4			6			
5) Embayment	39.13.57.0	81.41.10.8				15		1, 17
6) Wing Dam	39.22.16.1	81.24.04.8					11	
7) shoreline below Lee Cr.	39.08.54.0	81.44.29.4					9	
8) River Mile 170 DH #3	39.23.49.1	81.25.24.0					11	2
9) River Mile 170 DH #4	39.24.10.0	81.25.52.5					11	2

Table 3-3. Mean depths of transects with standard deviations, SD, (based on randomly-selected depths from each transect).

Site, by habitat	Transect	Mean depth (m)	SD
Tributary			
Bull Cr.	1	3.53	1.07
Duck Cr.	1	4.7	1.32
Hocking R.	1	6.87	0.78
	2	7.56	1.5
	3	6.95	0.74
Lee Cr.	1	5.04	1.43
	2	3.91	1.43
L. Hocking R.	1	3.85	1.26
L. Kanawha R.	1	8.69	0.66
	2	9.04	0.35
	3	9.06	0.46
Backwater			
Blennerhasset Is.	1	5.12	0.49
	2	8.94	0.25
	3	3.2	0.62
Halfway Is.	1	4.58	1.03
	2	6.36	0.23
	3	5.16	0.5
Neal Is.	1	5.84	0.47
	2	7.51	0.17
	3	5.2	0.47
Newberry Is.	1	7.26	0.43
	2	6.44	0.35
	3	3.48	0.54
Marietta Is.	1	4.54	0.48
	2	5.17	0.49
	3	3.31	0.59
Muskingum Is.	1	4.64	0.52
	2	5.16	0.49
	3	4.42	0.6

Table 3-3. Continued.

Island Head			
Blennerhasset Is.	1	2.77	0.44
	2	2.71	0.4
	3	2.06	0.21
Halfway Is.	1	2.51	0.42
	2	2.72	0.36
Neal Is.	1	4.52	0.43
	2	2.57	0.36
	3	2.74	0.36
Newberry Is.	1	2.66	0.35
	2	2.81	0.36
	3	2.02	0.3
Marietta Is.	1	2.85	0.37
	2	2.1	0.26
	3	2.83	0.48
Muskingum Is.	1	2.88	0.42
	2	2.87	0.43
	3	3.73	0.47
Island Tail			
Blennerhasset Is.	1	2.5	0.25
	2	2.08	0.28
	3	2.98	0.34
Halfway Is.	1	2.93	0.41
	2	3.02	0.43
Neal Is.	1	3.28	0.41
	2	3.4	0.44
	3	2.12	0.23
Newberry Is.	1	2.01	0.35
	2	2.11	0.25
Marietta Is.	1	2.05	0.29
	2	2.96	0.32
	3	2.03	0.31
Muskingum Is.	1	2.96	0.24
	2	3	0.29
	3	2.95	0.26

Table 3-3. Continued.

Main Channel			
River Mile 165	1	4	0.39
	2	7.64	0.3
	3	3.92	0.48
River Mile 167	1	5.19	0.38
	2	6.28	0.37
	3	8.75	0.53
River Mile 180	1	4.8	0.47
	2	9	0.61
	3	6.75	0.74
River Mile 184	1	7.4	0.54
	2	9.5	0.51
	3	7.47	0.41
River Mile 192	1	3.92	0.43
	2	7.98	0.48
	3	3.17	0.6
River Mile 194	1	3.85	0.55
	2	9.56	0.48
	3	3.77	0.43
Deep hole			
River Mile 170 #1	1	8.66	0.65
River Mile 170 #2	1	8.83	0.45
River Mile 170 #3	1	7.96	0.76
River Mile 170 #4	1	7.75	0.5
River Mile 180	1	10.51	0.47
River Mile 198	1	13.19	1.15

Table 3-4. Habitat data by site and habitat type for sample sessions from February 2002 through March 2003 in Belleville Pool, Ohio River (* indicates data not available). Dissolved oxygen (DO), pH, specific conductivity, and turbidity are average values from 1 m depth profiles.

Site	Habitat	Date	Temp (C)	DO (mg/L)	pH	sp. Cond. uS/cm	Flow (m/s)	Turb. (NTU)	Secchi (m)
Lee Cr.	tributary	2/16/2002	4.65	13.45	7.38	295	0.07	*	*
Lee Cr.	tributary	2/22/2002	5.36	13.12	7.8	354.3	*	*	*
Lee Cr.	tributary	4/4/2002	9.02	7.86	7.2	250.9	0	*	*
Lee Cr.	tributary	4/7/2002	8.84	9.86	7.26	251.7	0.15	*	*
Lee Cr.	tributary	12/15/2002	4.51	6.63	6.8	317.4	0.10	160.8	0.2
Lee Cr.	tributary	1/18/2003	1.44	13.81	7.5	427.4	0.03	17.5	0.94
Lee Cr.	tributary	3/1/2003	1.98	11.66	6.7	214.5	0.01	37	0.53
Hocking R.	tributary	2/16/2002	4.56	13.04	7.6	467.8	0.05	*	*
Hocking R.	tributary	2/22/2002	5.03	13.43	7.62	495.9	*	*	*
Hocking R.	tributary	4/4/2002	10.97	6.6	7.45	421.5	0.06	*	*
Hocking R.	tributary	4/7/2002	9.06	8.97	7.49	434.2	0.1	*	*
Hocking R.	tributary	12/15/2002	3.41	6.48	6.7	437.0	0.20	167.6	0.15
Hocking R.	tributary	1/18/2003	0.86	13.06	7.40	508.1	0.00	8.5	0.72
Hocking R.	tributary	3/1/2003	2.86	11.39	6.7	387.3	0.29	27	0.51
L. Hocking R.	tributary	2/17/2002	4.6	13.64	7.49	337.5	0.04	*	*
L. Hocking R.	tributary	4/5/2002	9.59	10.05	7.34	287.1	0.05	*	*
L. Hocking R.	tributary	4/7/2002	9.07	12.5	7.31	319.2	0.08	*	*
L. Hocking R.	tributary	12/16/2002	4.05	*	7.3	311.8	0.06	42.7	0.3
L. Hocking R.	tributary	1/13/2003	2.52	13.71	7.6	432.3	0.04	26.3	0.52
L. Hocking R.	tributary	3/17/2003	6.54	12.43	7.4	400.4	0.00	94	0.19
L. Kanawha R.	tributary	3/15/2002	7.58	8.19	7.42	283	0.05	*	*
L. Kanawha R.	tributary	4/5/2002	10.15	9.65	7.08	89.3	0.1	*	*
L. Kanawha R.	tributary	4/14/2002	13.07	10.56	7.19	200.4	0.14	*	*
L. Kanawha R.	tributary	12/16/2002	5.03	*	7.2	171.3	0.35	63.9	0.34
L. Kanawha R.	tributary	1/19/2003	0.83	14.13	7.8	327.3	0.06	9.3	1.61
L. Kanawha R.	tributary	3/16/2003	6.35	11.36	7.4	315.8	0.15	25	0.78
Bull Cr.	tributary	3/25/2002	7.53	8.21	7.32	292.6	0.03	*	*
Bull Cr.	tributary	4/6/2002	8.9	10.09	7.2	241.9	0.21	*	*
Bull Cr.	tributary	4/15/2002	12.85	9.59	7.28	217.1	0	*	*
Bull Cr.	tributary	12/12/2002	3.04	7.64	8.0	366.8	0.03	7.8	1.54
Bull Cr.	tributary	1/11/2003	3.24	13.55	7.2	397.0	0.23	69.4	0.33
Bull Cr.	tributary	3/2/2003	2.67	12.60	7.5	306.0	0.05	101	0.24
Duck Cr.	tributary	3/9/2002	6.64	8.97	7.42	389.6	0	*	*
Duck Cr.	tributary	3/24/2002	6.82	7.98	7.37	355.1	0	*	*
Duck Cr.	tributary	4/6/2002	8.94	10.12	7.25	244.4	0.72	*	*
Duck Cr.	tributary	4/15/2002	16.3	7.79	7.52	597.3	0.09	*	*
Duck Cr.	tributary	12/12/2002	4.39	7.45	7.1	414.8	0.03	3.3	0.22
Duck Cr.	tributary	1/11/2003	2.68	13.86	7.2	430.7	0.00	43.6	0.43
Duck Cr.	tributary	3/2/2003	3.88	11.38	7.1	499.6	0.28	93	0.24
Moore's Run	tributary	3/24/2002	6.28	8.15	7.43	324.1	0	*	*
Sugarcamp Run	tributary	3/24/2002	7.42	8.04	7.26	325.2	0.34	*	*
Sugarcamp Run	tributary	1/12/2003	3.23	13.55	7.4	402.8	0.05	51	0.32
Williams Two-Mile Cr.	tributary	3/24/2002	5.57	7.31	7	244.1	0	*	*

Table 3-4. Continued.

Site	Habitat	Date	Temp (C)	DO (mg/L)	pH	sp. Cond. uS/cm	Flow (m/s)	Turb. (NTU)	Secchi (m)
Newberry	island tail	3/11/2002	5.93	7.86	7.5	359.7	0.19	*	*
Newberry	island tail	4/5/2002	8.71	10.78	7.44	253.4	0.32	*	*
Newberry	island tail	4/7/2002	8.76	10.11	7.26	254.3	0.32	*	*
Newberry	island tail	12/15/2002	4.66	9.57	6.6	316.0	0.20	133.0	0.18
Newberry	island tail	1/18/2003	1.51	13.40	7.52	433.7	0.10	6.1	1.31
Newberry	island tail	3/1/2003	2.23	12.78	6.9	356.3	0.29	113	0.29
Newberry	island head	3/11/2002	8.71	7.73	7.5	356.8	0.21	*	*
Newberry	island head	4/5/2002	8.75	10.56	7.44	252.6	0.41	*	*
Newberry	island head	4/7/2002	8.75	12.19	7.29	252.4	0.41	*	*
Newberry	island head	12/15/2002	4.73	7.44	6.7	293.9	1.00	175.3	0.118
Newberry	island head	1/18/2003	1.51	13.12	7.52	433.0	0.19	6.1	1.31
Newberry	island head	3/1/2003	2.20	12.96	7.0	365.3	0.49	105	0.49
Blennerhasset	island tail	3/14/2002	7.45	9.33	7.96	403.9	0.04	*	*
Blennerhasset	island tail	4/5/2002	8.96	10.75	7.13	255	0.3	*	*
Blennerhasset	island tail	4/14/2002	11.95	11.89	7.34	310.9	0.08	*	*
Blennerhasset	island tail	12/16/2002	3.57	*	7.3	488.0	0.21	49.2	0.49
Blennerhasset	island tail	1/19/2003	1.21	12.15	7.6	456.3	0.06	12.5	1.02
Blennerhasset	island tail	3/17/2003	5.31	13.63	7.6	475.0	0.37	66	0.32
Blennerhasset	island head	3/14/2002	7.61	9.19	7.94	408.2	0.2	*	*
Blennerhasset	island head	4/5/2002	8.96	10.49	7.12	245.3	0.48	*	*
Blennerhasset	island head	4/14/2002	12.03	11.64	7.46	317.6	0.42	*	*
Blennerhasset	island head	12/16/2002	3.59	*	7.3	463.0	0.60	48.8	0.31
Blennerhasset	island head	1/19/2003	1.23	13.60	7.8	459.7	0.18	7.5	1.31
Blennerhasset	island head	3/17/2003	5.39	13.78	7.7	471.5	0.82	74	0.22
Neal	island tail	3/24/2002	7.14	8.05	7.18	332.3	0.27	*	*
Neal	island tail	4/5/2002	8.98	10.38	7.23	247	0.68	*	*
Neal	island tail	4/14/2002	11.6	11.7	7.43	272.1	0.09	*	*
Neal	island tail	12/17/2002	3.72	*	7.2	420.3	0.00	60.0	0.35
Neal	island tail	1/10/2003	3.54	13.50	7.2	405.0	0.12	60	0.46
Neal	island tail	3/16/2003	4.85	12.66	7.2	461.5	0.56	43	0.26
Neal	island head	3/24/2002	7.26	8.1	7.18	329.3	0.45	*	*
Neal	island head	4/5/2002	8.98	10.43	7.22	249.2	0.98	*	*
Neal	island head	4/14/2002	11.54	11.85	7.36	274.3	0.65	*	*
Neal	island head	12/17/2002	3.61	*	7.2	423.0	0.66	80.3	0.32
Neal	island head	1/10/2003	3.56	13.48	7.1	406.0	0.62	44.7	0.44
Neal	island head	3/16/2003	4.82	13.17	7.2	466.8	0.98	43	0.24
Halfway	island tail	3/24/2002	7.46	8.31	7.47	404.9	0.3	*	*
Halfway	island tail	4/6/2002	9.62	10.22	7.57	371.8	0.16	*	*
Halfway	island tail	4/15/2002	14.48	9.04	7.62	432.3	0.43	*	*
Halfway	island tail	12/17/2002	3.66	*	7.1	538.0	0.26	39.9	0.42
Halfway	island tail	1/10/2003	3.29	13.48	7.1	506.0	0.23	38.6	0.49
Halfway	island tail	3/16/2003	4.98	12.84	7.3	532.0	0.34	139	0.18
Halfway	island head	3/24/2002	7.49	8.23	7.57	403.6	0.48	*	*
Halfway	island head	4/6/2002	9.57	10.21	7.6	373	0.83	*	*
Halfway	island head	4/15/2002	14.47	9.12	7.61	369.2	0.56	*	*
Halfway	island head	12/17/2002	3.66	*	7.3	540.0	0.57	43.4	0.42
Halfway	island head	1/10/2003	3.28	13.37	7.2	507.5	0.50	36.4	0.42
Halfway	island head	3/16/2003	5.09	12.73	7.5	539.7	0.82	134	0.18

Table 3-4. Continued.

Site	Habitat	Date	Temp (C)	DO (mg/L)	pH	sp Cond. uS/cm	Flow (m/s)	Turb. (NTU)	Secchi (m)
Muskingum	island tail	3/24/2002	7.51	8.04	7.24	338.4	0.65	*	*
Muskingum	island tail	4/6/2002	8.92	10.66	7.05	246.3	0.76	*	*
Muskingum	island tail	4/15/2002	11.92	9.85	7.44	284	0	*	*
Muskingum	island tail	12/13/2002	4.47	8.47	7.2	443.0	0.23	6.5	1.35
Muskingum	island tail	1/10/2003	3.59	13.49	7.3	407.0	0.21	45.6	0.41
Muskingum	island tail	3/16/2003	5.01	13.17	7.4	480.0	0.18	38	0.42
Muskingum	island head	3/24/2002	7.51	8.12	7.24	335.2	1.02	*	*
Muskingum	island head	4/6/2002	8.91	10.58	7.08	246.2	0.86	*	*
Muskingum	island head	4/15/2002	11.58	10.35	7.32	264.2	0.96	*	*
Muskingum	island head	12/17/2002	3.56	*	7.2	427.0	0.84	66.8	0.36
Muskingum	island head	1/19/2003	1.23	13.52	7.8	457.0	0.15	10.8	1.25
Muskingum	island head	3/16/2003	4.97	13.20	7.5	483.3	1.13	42	*
Marietta	island tail	3/25/2002	7.31	8.25	7.27	288.3	0.26	*	*
Marietta	island tail	4/6/2002	9.04	10.38	7.2	241	0.38	*	*
Marietta	island tail	4/15/2002	11.71	10.9	7.45	267.3	0.73	*	*
Marietta	island tail	12/12/2002	4.81	7.38	7.2	400.0	0.10	3.1	1.5
Marietta	island tail	1/12/2003	3.15	13.89	7.3	397.0	0.04	32.8	0.42
Marietta	island tail	3/2/2003	2.31	13.00	7.4	366.0	0.57	114	0.24
Marietta	island head	3/25/2002	7.3	8.32	7.27	286.5	0.46	*	*
Marietta	island head	4/6/2002	8.89	10.41	7.22	242.6	0.54	*	*
Marietta	island head	4/15/2002	11.88	10.7	7.35	268.8	0.86	*	*
Marietta	island head	12/12/2002	4.59	7.24	7.2	400.0	0.16	3.2	2.01
Marietta	island head	1/12/2003	3.10	13.49	7.3	395.0	0.43	31.2	0.49
Marietta	island head	3/2/2003	2.31	13.34	7.4	365.0	0.60	114	0.24
River Mile 194	main channel	3/14/2002	7.44	9.07	7.8	393.4	0.13	*	*
River Mile 194	main channel	4/5/2002	8.7	10.56	7.44	252.6	0.41	*	*
River Mile 194	main channel	4/7/2002	8.8	12.33	7.25	243.6	0.55	*	*
River Mile 194	main channel	12/16/2002	3.70	*	7.2	523.0	0.60	36.8	0.2
River Mile 194	main channel	1/18/2003	1.23	12.05	7.56	434.3	0.05	10.9	1.14
River Mile 194	main channel	3/1/2003	2.38	12.62	7.0	366.2	0.22	93	0.2
River Mile 192	main channel	3/14/2002	7.24	9.07	7.8	393.4	0.13	*	*
River Mile 192	main channel	4/5/2002	8.7	10.49	7.44	253.2	0.4	*	*
River Mile 192	main channel	4/7/2002	8.84	12.29	7.24	256.4	0.69	*	*
River Mile 192	main channel	12/16/2002	3.70	*	7.2	523.0	0.60	36.8	0.2
River Mile 192	main channel	1/13/2003	2.63	13.90	7.5	462.4	0.33	28.3	0.52
River Mile 192	main channel	3/17/2003	5.30	13.26	7.5	492.6	0.70	110	0.16
River Mile 184	main channel	3/24/2002	7.28	8.25	7.28	335	0.42	*	*
River Mile 184	main channel	4/6/2002	8.98	10.38	7.23	247	0.95	*	*
River Mile 184	main channel	4/14/2002	11.5	11.65	7.38	267.7	0.53	*	*
River Mile 184	main channel	12/17/2002	3.75	*	6.9	496.8	0.81	41.6	0.32
River Mile 184	main channel	1/19/2003	1.49	13.76	7.7	471.0	0.13	11.2	1.26
River Mile 184	main channel	3/16/2003	4.74	12.60	7.3	494.3	1.25	83	0.26
River Mile 180	main channel	3/24/2002	7.27	8.07	7.27	333.7	0.48	*	*
River Mile 180	main channel	4/6/2002	8.98	10.32	7.3	249.9	1.13	*	*
River Mile 180	main channel	4/15/2002	11.66	8.07	7.27	333.7	0.48	*	*
River Mile 180	main channel	12/17/2002	3.66	*	7.0	421.9	0.78	75.3	0.31
River Mile 180	main channel	1/10/2003	3.58	13.45	7.4	404.5	0.84	41.7	*
River Mile 180	main channel	3/16/2003	4.85	12.87	7.3	498.0	1.00	91	0.22
River Mile 176	main channel	4/6/2002	9.35	10.18	7.49	363.2	0.79	*	*

Table 3-4. Continued.

Site	Habitat	Date	Temp (C)	DO (mg/L)	pH	sp. Cond. uS/cm	Flow (m/s)	Turb. (NTU)	Secchi (m)
River Mile 167	main channel	3/25/2002	7.3	8.25	7.27	288.3	0.46	*	*
River Mile 167	main channel	4/6/2002	9.02	10.43	7.18	244.7	0.63	*	*
River Mile 167	main channel	4/15/2002	12	10.3	7.26	273.5	1.15	*	*
River Mile 167	main channel	12/12/2002	4.62	7.18	7.2	399.0	0.23	3	2
River Mile 167	main channel	1/12/2003	3.21	13.56	7.4	401.0	0.43	32.1	0.54
River Mile 167	main channel	3/2/2003	3.92	10.37	7.3	400.0	0.21	18	0.18
River Mile 165	main channel	3/25/2002	7.3	8.22	7.27	288.3	0.45	*	*
River Mile 165	main channel	4/6/2002	8.98	10.35	7.25	246.8	0.79	*	*
River Mile 165	main channel	4/15/2002	12	10.29	7.26	272.5	1.11	*	*
River Mile 165	main channel	12/12/2002	4.60	7.34	7.3	398.0	0.23	3.3	1.85
River Mile 165	main channel	1/12/2003	3.10	13.58	7.9	397.2	0.39	3.6	0.42
River Mile 165	main channel	3/2/2003	2.42	12.86	7.3	361.3	0.37	111	0.2
River Mile 198	deep hole	2/22/2002	5.42	13.64	7.55	373	*	*	*
River Mile 198	deep hole	3/14/2002	7.24	9.07	7.8	393.4	*	*	*
River Mile 198	deep hole	4/7/2002	8.83	12.25	7.24	258.3	*	*	*
River Mile 198	deep hole	12/15/2002	3.70	*	7.2	523.0	0.60	36.8	0.2
River Mile 198	deep hole	1/18/2003	1.55	12.48	7.6	431.1	0.15	11.3	1.1
River Mile 198	deep hole	3/1/2003	2.32	12.44	7.0	349.7	0.35	97	0.18
River Mile 180	deep hole	3/24/2002	7.26	8.07	7.27	333.7	0.48	*	*
River Mile 180	deep hole	4/6/2002	8.98	10.32	7.3	249.9	1.13	*	*
River Mile 180	deep hole	4/15/2002	11.66	8.07	7.27	333.7	0.48	*	*
River Mile 180	deep hole	12/17/2002	3.66	*	7.0	421.9	0.78	75.3	0.31
River Mile 180	deep hole	1/10/2003	3.58	13.45	7.4	404.5	0.84	41.7	*
River Mile 180	deep hole	3/16/2003	4.85	12.87	7.3	498.0	1.00	91	0.22
River Mile 170 #1	deep hole	3/25/2002	7.3	8.32	7.27	286.5	0.39	*	*
River Mile 170 #1	deep hole	4/6/2002	8.99	10.3	7.17	244.4	0.92	*	*
River Mile 170 #1	deep hole	4/15/2002	11.87	10.7	7.35	268.8	0.82	*	*
River Mile 170 #1	deep hole	12/13/2002	4.49	8.38	7.3	371.8	0.43	4.5	*
River Mile 170 #1	deep hole	1/11/2003	3.23	13.71	7.5	398.0	0.64	39.9	0.42
River Mile 170 #1	deep hole	3/2/2003	2.31	12.87	7.2	363.0	0.60	116	0.21
River Mile 170 #2	deep hole	12/13/2002	4.49	8.38	7.3	371.8	0.43	4.5	*
River Mile 170 #2	deep hole	1/11/2003	3.23	13.71	7.5	398.0	0.64	39.9	0.42
River Mile 170 #2	deep hole	3/2/2003	2.31	12.87	7.2	363.0	0.60	116	0.21
River Mile 170 #3	deep hole	12/13/2002	4.49	8.38	7.3	371.8	0.43	4	*
River Mile 170 #3	deep hole	1/11/2003	3.23	13.71	7.5	398.0	0.64	40	0.42
River Mile 170 #3	deep hole	3/2/2003	2.32	13.22	7.2	363.3	0.61	121	0.25
River Mile 170 #4	deep hole	12/13/2002	4.49	8.38	7.3	371.8	0.43	4	*
River Mile 170 #4	deep hole	1/11/2003	3.23	13.71	7.5	398.0	0.64	40	0.42
River Mile 170 #4	deep hole	3/2/2003	2.32	13.22	7.2	363.3	0.61	121	0.25
Newberry	backwater	3/11/2002	4.4	7.74	7.5	356.2	0.2	*	*
Newberry	backwater	4/5/2002	8.7	10.78	7.44	253.4	0.32	*	*
Newberry	backwater	4/7/2002	8.74	10.07	7.26	243.6	0.67	*	*
Newberry	backwater	12/15/2002	4.73	7.44	6.7	293.9	1.00	175.3	0.18
Newberry	backwater	1/18/2003	1.57	13.00	7.52	432.6	0.06	11	1.36
Newberry	backwater	3/1/2003	2.31	12.68	6.8	345.0	0.59	99	0.22
Blennerhasset	backwater	3/14/2002	7.1	9.14	7.78	366.5	0.14	*	*
Blennerhasset	backwater	4/5/2002	8.96	10.75	7.13	255	0.44	*	*
Blennerhasset	backwater	4/14/2002	11.86	11.3	7.44	288.5	0.33	*	*
Blennerhasset	backwater	12/16/2002	3.59	*	7.3	463.0	0.60	48.8	0.29

Table 3-4. Continued.

Site	Habitat	Date	Temp (C)	DO (mg/L)	pH	sp. Cond. uS/cm	Flow (m/s)	Turb. (NTU)	Secchi (m)
Blennerhasset	backwater	1/19/2003	1.18	13.35	7.8	453.3	0.16	11.7	1.1
Blennerhasset	backwater	3/17/2003	5.18	13.68	7.5	463.4	0.69	56	0.32
Neal	backwater	3/15/2002	7.42	9.13	7.56	382.3	0.18	*	*
Neal	backwater	4/6/2002	8.98	10.38	7.23	247	0.93	*	*
Neal	backwater	4/14/2002	11.46	11.83	7.42	260.8	0.63	*	*
Neal	backwater	12/17/2002	3.66	*	7.2	419.0	0.66	72.8	0.34
Neal	backwater	1/10/2003	3.54	13.49	7.3	404.2	0.59	44.9	0.45
Neal	backwater	3/16/2003	4.81	12.94	7.2	459.1	0.64	39	0.39
Halfway	backwater	3/24/2002	7.49	8.23	7.57	403.6	0.42	*	*
Halfway	backwater	4/6/2002	9.81	10.28	7.57	381.9	0.77	*	*
Halfway	backwater	4/15/2002	14.47	9.04	7.62	432.3	0.76	*	*
Halfway	backwater	12/17/2002	4.54	*	7.2	568.3	0.50	36.3	0.41
Halfway	backwater	1/10/2003	4.03	13.42	7.1	539.0	0.49	36	0.48
Halfway	backwater	3/16/2003	5.13	12.70	7.3	534.7	0.60	136	0.18
Muskingum	backwater	3/24/2002	7.5	8.04	7.24	338.4	0.92	*	*
Muskingum	backwater	4/6/2002	8.91	10.58	7.08	246.2	0.76	*	*
Muskingum	backwater	4/15/2002	11.58	10.35	7.32	264.2	0.82	*	*
Muskingum	backwater	12/17/2002	3.71	*	7.1	425.0	0.81	70.1	0.36
Muskingum	backwater	1/19/2003	1.18	13.36	7.8	453.7	0.18	10.8	1.22
Muskingum	backwater	3/16/2003	4.99	13.18	7.3	476.8	0.95	37	*
Marietta	backwater	3/25/2002	7.3	8.32	7.27	286.5	0.39	*	*
Marietta	backwater	4/6/2002	8.99	10.3	7.17	244.4	0.92	*	*
Marietta	backwater	4/15/2002	11.87	10.7	7.35	268.8	0.82	*	*
Marietta	backwater	12/13/2002	4.49	8.38	7.3	371.8	0.43	4.5	*
Marietta	backwater	1/11/2003	3.23	13.71	7.6	398.0	0.64	39.9	0.42
Marietta	backwater	3/2/2003	2.37	13.06	7.2	360.2	0.62	116	0.24
L. Sandy Cr.	embayment	12/15/2002	4.08	7.41	6.9	257.3	0.00	65.8	*
L. Sandy Cr.	embayment	3/1/2003	2.95	11.16	7.3	257.0	0	55.00	0.39
L. Sandy Cr.	embayment	3/17/2003	11.24	11.75	7.7	350.0	0	84.00	0.25
Wing Dam	artificial	1/11/2003	3.26	14.61	7.2	400.7	0.10	50	37

Table 3-5. Sites of temperature loggers in Belleville Pool, Ohio River, during 2002 and 2003. Loggers at river mile 196 and Neal Island were not recovered in 2003.

Site Location	Habitat	Water column placement
Blennerhasset Is.	Backwater	Bottom
Newberry Is.	Backwater	Bottom
Neal Is.	Backwater	Bottom
River Mile 196	Main channel	Near surface
River Mile 184	Main channel	Near surface
Marietta Is. Head	Main channel	Near surface

Table 3-6. Total number of fishes caught at each habitat type in the Belleville Pool, Ohio River, during sample sessions from February 2002 – March 2003.

Species	Island Head	Island Tail	Back water	Main	Tributary	Deep hole	Wing Dam	Embay-ment	Total
Black Buffalo	0	0	0	0	0	0	1	0	1
Black Crappie	0	0	0	0	1	0	0	2	3
Bluegill	0	0	0	0	1	0	0	164	165
Bowfin	0	0	0	0	0	0	0	1	1
Channel Catfish	6	2	43	62	88	1	0	0	202
Common Carp	0	1	3	2	6	0	1	3	16
Emerald Shiner	0	0	0	0	7	0	2	137	146
Flathead Catfish	0	0	0	1	0	0	0	0	1
Freshwater Drum	3	3	26	157	270	3	7	6	475
Gizzard Shad	0	0	2	13	60	0	1	430	506
Golden Redhorse	0	0	0	0	1	0	0	0	1
Green Sunfish	0	0	0	0	0	0	0	7	7
Highfin Carpsucker	0	0	0	0	4	0	0	0	4
Hybrid Striped Bass	0	0	0	6	14	0	0	0	20
Largemouth Bass	0	0	0	1	0	0	0	3	4
Mooneye	0	5	7	4	2	0	0	0	18
Mosquitofish	0	0	0	0	0	0	0	1	1
Ohio Lamprey	0	0	1	0	0	0	0	0	1
Orangespotted Sunfish	0	0	0	0	1	0	0	49	50
Pumpkinseed	0	0	0	0	0	0	0	5	5
Quillback	0	0	0	0	4	0	0	0	4
River Carpsucker	0	0	2	2	21	0	1	4	30
Rock Bass	0	0	1	0	0	0	0	0	1
Sauger	0	1	0	0	2	0	0	0	3
Shorthead Redhorse	0	0	0	1	0	0	1	0	2
Silver Chub	0	4	4	6	0	0	0	0	14
Smallmouth Buffalo	0	2	10	12	30	0	12	1	67
Spottail Shiner	0	0	0	0	1	0	0	0	1
Spotted Bass	0	0	0	0	0	2	0	0	2
Spotted Sucker	0	0	0	0	0	0	0	2	2
Walleye	0	0	0	0	3	0	0	0	3
Warmouth	0	0	0	0	0	0	0	5	5
White Bass	1	0	3	4	37	0	1	0	46
White Crappie	0	0	0	1	0	0	0	70	71
Total	10	18	102	272	553	6	27	890	1878

Table 3-7. Total number of fishes caught at each habitat type in the Belleville Pool, Ohio River, during sample sessions from February – April 2002.

Species	Island Head	Island Tail	Back water	Main	Tributary	Deep hole	Total
Bluegill	0	0	0	0	1	0	1
Channel Catfish	6	2	17	19	75	0	119
Common Carp	0	0	0	0	4	0	4
Emerald Shiner	0	0	0	0	7	0	7
Flathead Catfish	0	0	0	1	0	0	1
Freshwater Drum	3	2	4	10	160	0	179
Gizzard Shad	0	0	0	1	57	0	58
Highfin Carpsucker	0	0	0	0	2	0	2
Mooneye	0	3	1	1	2	0	7
Orangespotted Sunfish	0	0	0	0	1	0	1
Quillback	0	0	0	0	2	0	2
River Carpsucker	0	0	0	0	15	0	15
Spottail Shiner	0	0	0	0	1	0	1
Walleye	0	0	0	0	2	0	2
White Bass	0	0	0	0	4	0	4
Total	9	7	22	32	333	0	403

Table 3-8. Fish caught per hour (CPUE) within each habitat type in the Belleville Pool, Ohio River, during February 2002 through March 2003.

	Habitat types								
Species	Island Head	Island Tail	Back water	Main channel	Trib	Deep hole	Wing dam	Embay-ment	Total
Black Buffalo	0	0	0	0	0	0	7.52	0.00	0.02
Black Crappie	0	0	0	0	0.16	0	0	1.36	0.06
Bluegill	0	0	0	0	0.16496	0	0	111.87	3.44
Bowfin	0	0	0	0	0	0	0	0.68	0.02
Channel Catfish	1.80	0	3.45	3.44	14.52	0.48	0	0.00	4.21
Common Carp	0	0.23	0.24	0.11	0.99	0	7.52	2.05	0.33
Emerald Shiner	0	0	0	0	1.15	0	15.04	93.45	3.05
Flathead Catfish	0	0	0	0	0	0	0	0.00	0.02
Freshwater Drum	0.90	0.69	2.08	8.71	44.54	1.43	52.63	4.09	9.91
Gizzard Shad	0	0	0.16	0.72	9.90	0	8	293.32	10.56
Golden Redhorse	0	0	0	0	0.16496	0	0	0.00	0.02
Green Sunfish	0	0	0	0	0	0	0	4.77	0.15
Highfin Carpsucker	0	0	0	0	0.66	0	0	0.00	0.08
Hybrid Striped Bass	0	0	0	0.33	2	0	0	0.00	0.42
Largemouth Bass	0	0.00	0.00	0.06	0	0	0	2.05	0.08
Mooneye	0	1.15	0.56	0.22	0.33	0	0	0.00	0.38
Mosquitofish	0	0	0	0	0	0	0	0.68	0.02
Ohio Lamprey	0	0	0.08	0	0	0	0	0.00	0.02
Orangespotted Sunfish	0	0	0	0	0	0	0	33.42	1.04
Pumpkinseed	0	0	0	0	0	0	0	3.41	0.10
Quillback	0	0	0	0	0.66	0	0	0.00	0.08
River Carpsucker	0	0	0.16	0.11	3	0	8	2.73	0.63
Rock Bass	0	0	0.08	0	0	0	0	0.00	0.02
Sauger	0	0	0	0	0.33	0	0	0.00	0.06
Shorthead Redhorse	0	0	0	0.06	0	0	8	0.00	0.04
Silver Chub	0	0.92	0.32	0.33	0	0	0	0.00	0.29
Smallmouth Buffalo	0	0.46	0.80	0.67	4.95	0	90	0.68	1.40
Spottail Shiner	0	0	0	0	0.16	0	0	0.00	0.02
Spotted Bass	0	0	0	0	0	0.95	0	0.00	0.04
Spotted Sucker	0	0	0	0	0	0	0	1.36	0.04
Walleye	0	0	0	0	0.49	0	0	0.00	0.06
Warmouth	0	0	0	0	0	0	0	3.41	0.10
White Bass	0.30	0	0.24	0.22	6.10	0	7.52	0.00	0.96
White Crappie	0	0	0	0.06	0	0	0	47.75	1.48
Total	2.99	4.12	8.17	15.09	91.22	2.86	203.01	607.09	39.18

Table 3-9. Fish caught per hour (CPUE) within each habitat type in the Belleville Pool, Ohio River, during February - April 2002.

	Habitat types						
	Island		Back	Main		Deep	
Species	Head	Tail	water	channel	Trib	hole	Total
Bluegill	0	0	0	0	0.34	0	0.05
Channel catfish	4.08	1.87	3.79	2.11	25.84	0	5.84
Common carp	0	0	0	0	1.38	0	0.19
Emerald shiner	0	0	0	0	2.76	0	0.39
Flathead catfish	0	0	0	0.11	0	0	0.05
Freshwater drum	2.04	0.93	0.89	1.11	55.12	0	8.64
Gizzard shad	0	0	0	0.11	19.64	0	2.80
Highfin carpsucker	0	0	0	0	0.69	0	0.10
Hybrid striped bass	0	0	0	0	1.38	0	0.19
Mooneye	0	1.40	0.22	0.11	0.69	0	0.34
Orangespotted Sunfish	0	0	0	0	0.34	0	0.05
Quillback	0	0	0	0	0.69	0	0.10
River carpsucker	0	0	0	0	5.17	0	0.72
Walleye	0	0	0	0	1	0	0.10
Total	6.12	4.20	4.91	3.55	114.73	0	19.55

Table 3-10. Fish caught per hour (CPUE) within each habitat type in the Belleville Pool, Ohio River, during December 2002 through March 2003.

	Habitat types								
	Island		Back	Main		Deep	Wing	Embay-	
Species	Head	Tail	water	channel	Trib	hole	dam	ment	Total
Black Buffalo	0	0	0	0	0	0	7.52	0.00	0.04
Black Crappie	0	0	0	0	0.32	0	0	1.36	0.11
Bluegill	0	0	0	0	0	0	0	111.87	6.10
Bowfin	0	0	0	0	0	0	0	0.68	0.04
Channel Catfish	0	0	3.29	4.77	4.11	0.87	0	0.00	3.09
Common Carp	0	0.45	0.38	0.22	0.63	0	7.52	2.05	0.45
Emerald Shiner	0	0	0	0	0	0	15.04	93.45	5.17
Freshwater Drum	0	0.45	2.78	16.32	34.81	2.60	52.63	4.09	11.01
Gizzard Shad	0	0	0.25316	1.33	0.95	0	7.52	293.32	16.67
Golden Redhorse	0	0	0	0	0.32	0	0	0.00	0.04
Green Sunfish	0	0	0	0	0	0	0	4.77	0.26
Highfin Carpsucker	0	0	0	0	0.63	0	0	0.00	0.07
Hybrid Striped Bass	0	0	0	0.67	3.16	0	0	0.00	0.60
Largemouth Bass	0	0	0	0.11	0	0	0	2.05	0.15
Mooneye	0	0.90	0.76	0.33	0	0	0	0.00	0.41
Mosquitofish	0	0	0	0	0	0	0	0.68	0.04
Ohio Lamprey	0	0	0.13	0	0	0	0	0.00	0.04
Orangespotted Sunfish	0	0	0	0	0	0	0	33.42	1.82
Pumpkinseed	0	0	0	0	0	0	0	3.41	0.19
Quillback	0	0	0	0	0.63	0	0	0.00	0.07
River Carpsucker	0	0	0.25	0.22	1.90	0	7.52	2.73	0.56
Rock Bass	0	0	0.13	0	0	0	0	0.00	0.04
Sauger	0	0.45	0	0	0.63	0	0	0.00	0.11
Shorthead Redhorse	0	0	0	0.11	0	0	7.52	0.00	0.07
Silver Chub	0	1.80	0.51	0.67	0	0	0	0.00	0.52
Smallmouth Buffalo	0	0.90	1.27	1.33	9.49	0	90.23	0.68	2.49
Spotted Bass	0	0	0	0	0	1.73	0	0.00	0.07
Spotted Sucker	0	0	0	0	0	0	0	1.36	0.07
Walleye	0	0	0	0	0.31646	0	0	0.00	0.04
Warmouth	0	0	0	0	0	0	0	3.41	0.19
White Bass	0.53	0	0.38	0.44	11.71	0	7.52	0.00	1.71
White Crappie	0	0	0	0.11	0	0	0	47.75	2.64
Total	0.53	4.95	10.13	26.64	69.62	5.20	203.008	607.09	54.89

Table 3-11. Selection statistics for occupancy rate models fit to freshwater drum data including the second order adjustment to Akaike's Information Criterion (AICc), rescaled differences (Delta AICc), Akaike model weights, model likelihoods, number of model parameters (K) and model deviance.

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	K	Model Deviance
{p(depth) psi(hab*yr)}	213.68	0	0.506	1	8	196.03
{p(.) psi(hab*yr)}	215.20	1.52	0.236	0.47	7	199.93
{p(flow) psi(hab*yr)}	217.03	3.35	0.095	0.19	8	199.37
{p(temp) psi(hab*yr)}	217.56	3.88	0.073	0.14	8	199.90
{p(cond) psi(hab*yr)}	217.58	3.90	0.072	0.14	8	199.93
{p(hab*yr) psi(hab*yr)}	220.27	6.59	0.019	0.04	12	192.51

Table 3-12. Actual and model-averaged estimates of the proportion of sites within three habitat types occupied by freshwater drum (ψ).

Habitats	Actual value with p = 1 ψ	SE	Model-averaged with p < 1 ψ	SE
Year 1				
Backwater	0.03	0.06	0.11	0.13
Main channel	0.11	0.08	0.42	0.27
Tributary	0.33	0.11	0.78	0.24
Year 2				
Backwater	0.15	0.06	0.36	0.37
Main channel	0.26	0.07	0.82	0.06
Tributary	0.21	0.10	0.56	0.33

Table 3-13. Results of gill net sampling at 11 sites on Belleville Pool. Site coordinates are in Table 3-2.

Site	Habitat Type	Date Set	Time Set	Date Pulled	Time Pulled	hours fished	Species captured: Mooneye	Sauger	Shorthead Redhorse	Carp
Bull Cr.	Tributary	12/12/2002	16:30	12/13/2002	10:00	17.5		2	1	
Marietta Is.	Is. Head	12/12/2002	16:45	12/13/2002	10:30	17.75				
River Mile 167	Main Channel	12/12/2002	16:15	12/13/2002	10:15	18				
Marietta Is. DH #1	Deep Hole	12/13/2002	13:20	1/12/2002	*	*				
Muskingum Is.	Is. Tail	12/13/2002	14:00	12/14/2002	13:40	23.6**				
Neal Is.	Is. Head	1/10/2003	12:00	1/10/2003	15:45	3.75				
Neal Is.	Is. Tail	1/10/2003	10:30	1/10/2003	16:15	5.75				
Neal Is.	Backwater	1/10/2003	11:30	1/10/2003	16:00	4.5	1			
Lee Cr.	Tributary	3/1/2003	11:30	3/1/2003	18:00	6.5				2
Hocking R.	Tributary	3/1/2003	12:15	3/1/2003	18:00	5.75				
Newberry Is.	Is. Tail	3/1/2003	13:00	3/1/2003	17:30	4.5				

*floats submerged during high flows in Dec., recovered in Jan., no fish present.

**Net tangled in LWD during high flows and cut into pieces during removal.

754

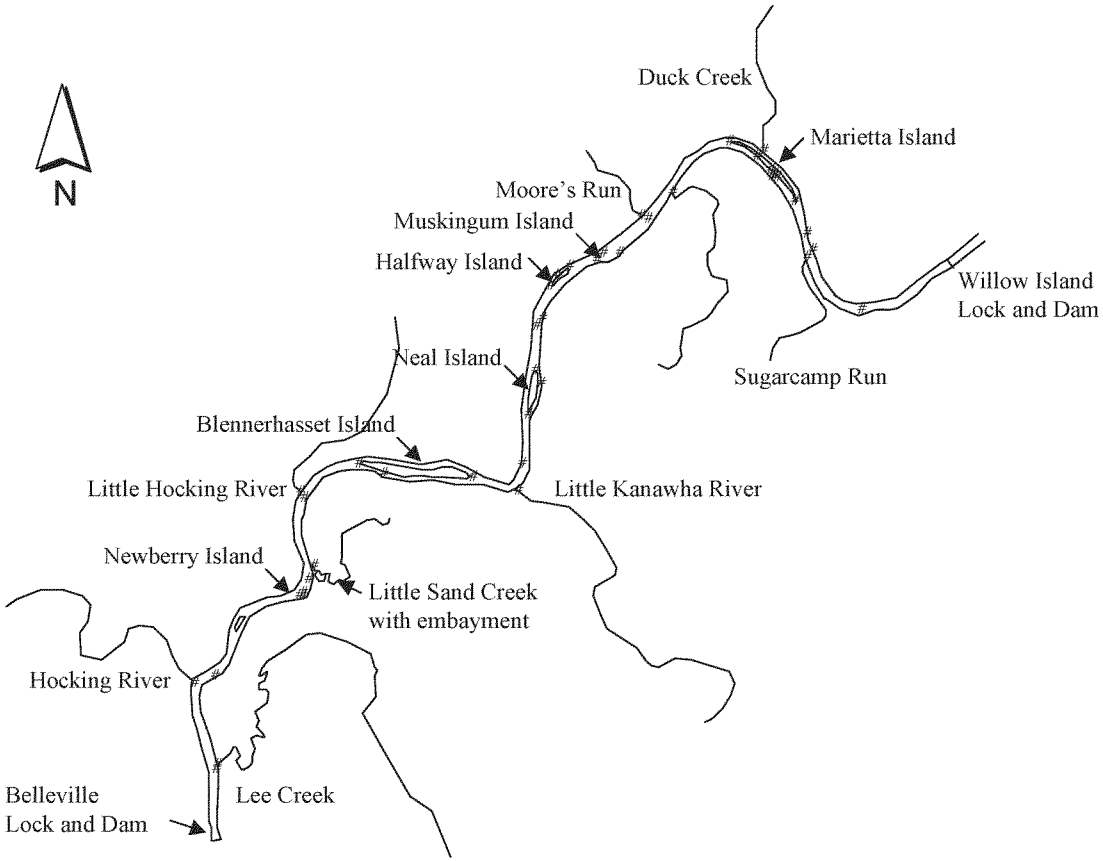
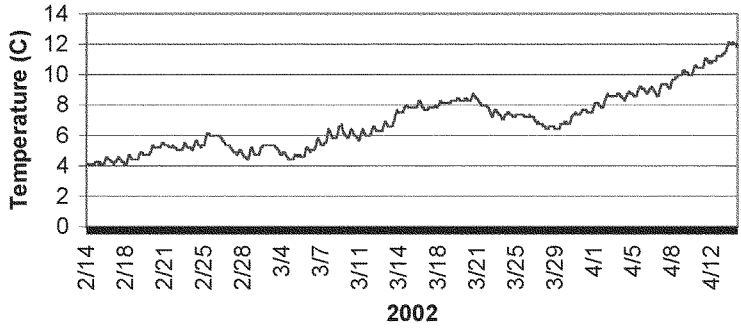


Figure 3-1. Locations of sample sites within Belleville Pool.

Figure 3-2. Temperature logger data from six sites in Belleville Pool, Ohio River, from 15 February 2002 to 15 April 2002.

Blennerhasset Island backwater



Newberry Island Backwater

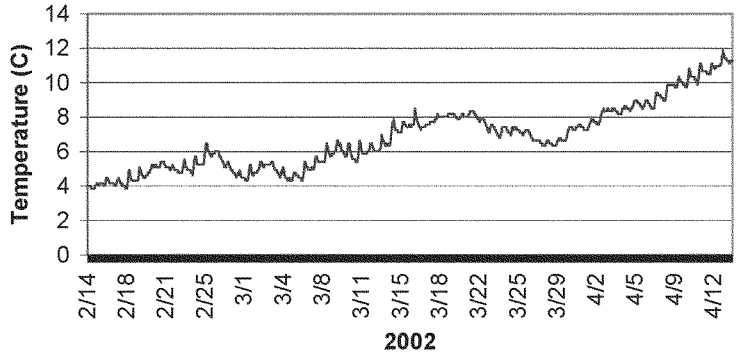
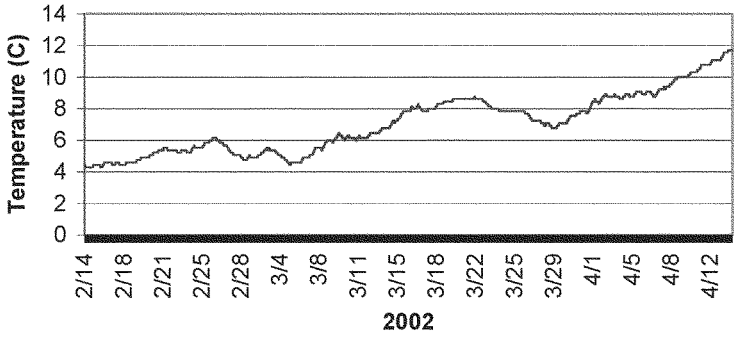


Figure 3-2. Continued

Neal Island backwater



Main channel river mile 196

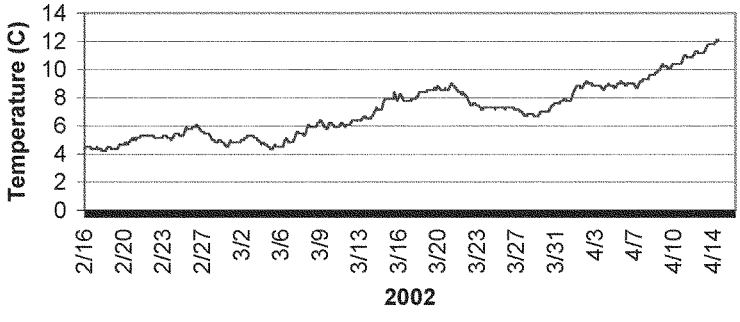
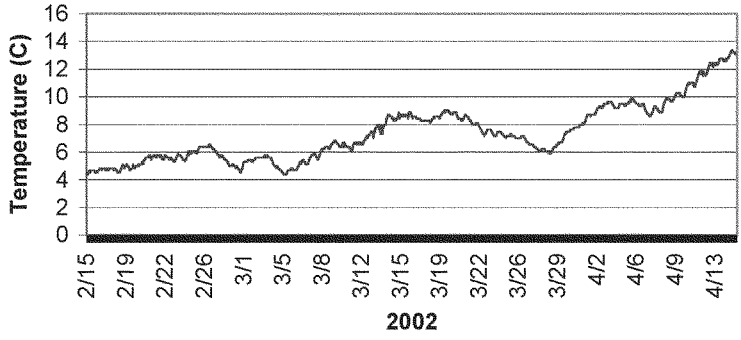


Figure 3-2. Continued

Main channel river mile 184



Marietta Island head

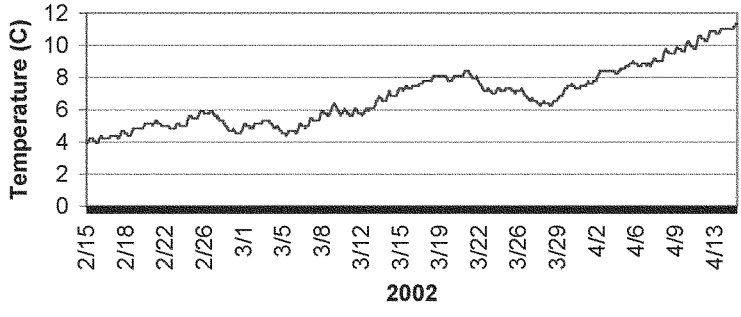
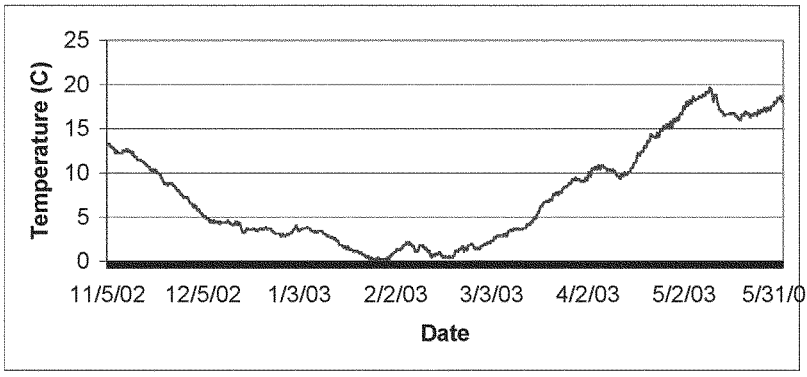


Figure 3-3. Temperature logger data from four sites in Belleville Pool, Ohio River, from winter 2002/2003.

Blennerhasset Island backwater



Newberry Island Backwater

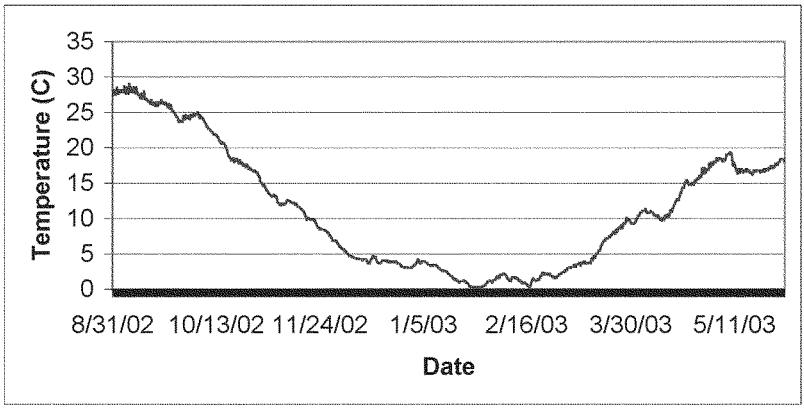
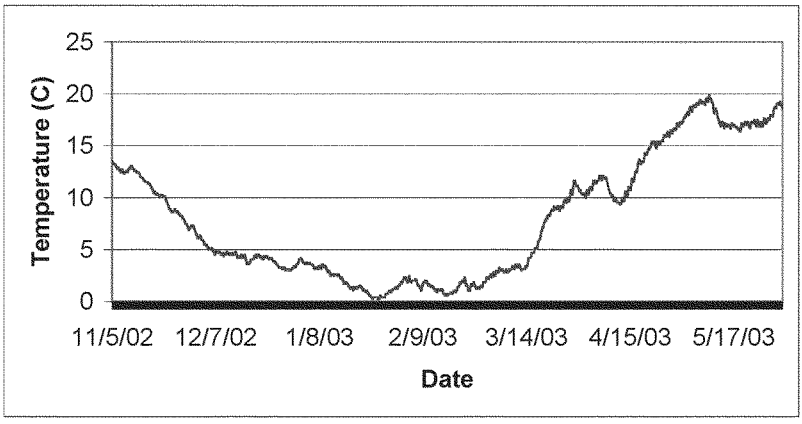
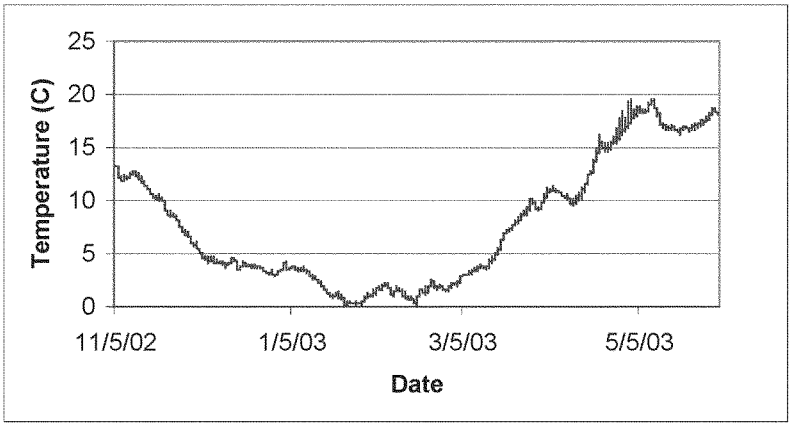


Figure 3-3. Continued.

Main channel river mile 184



Marietta Island head



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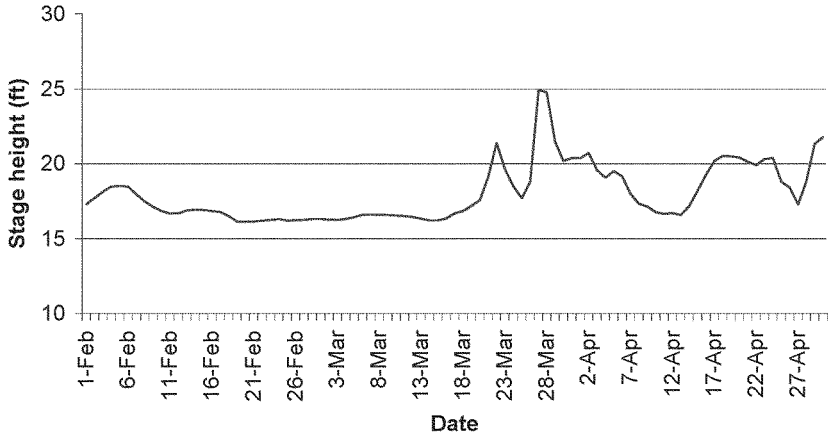

B

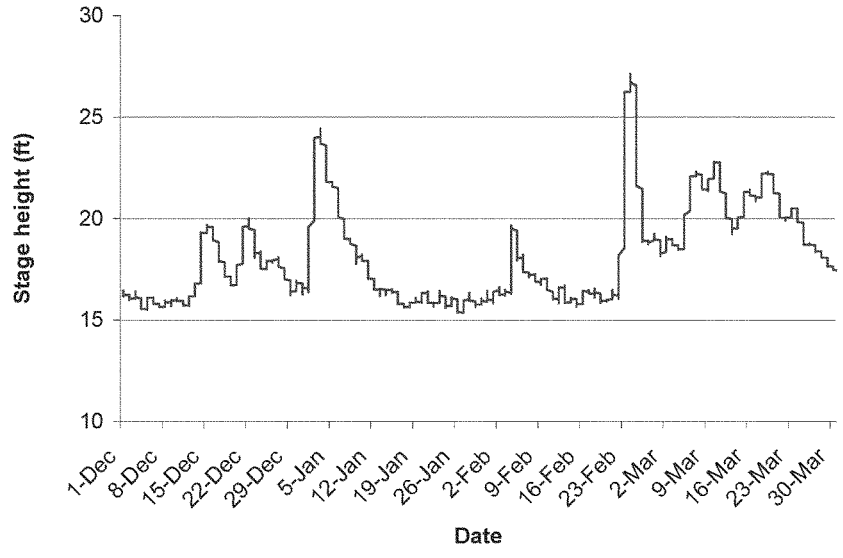

Figure 3-4. Stage data from Ohio River at Marietta during February through April 2002 (A) and December 2002 through March 2003 (B).

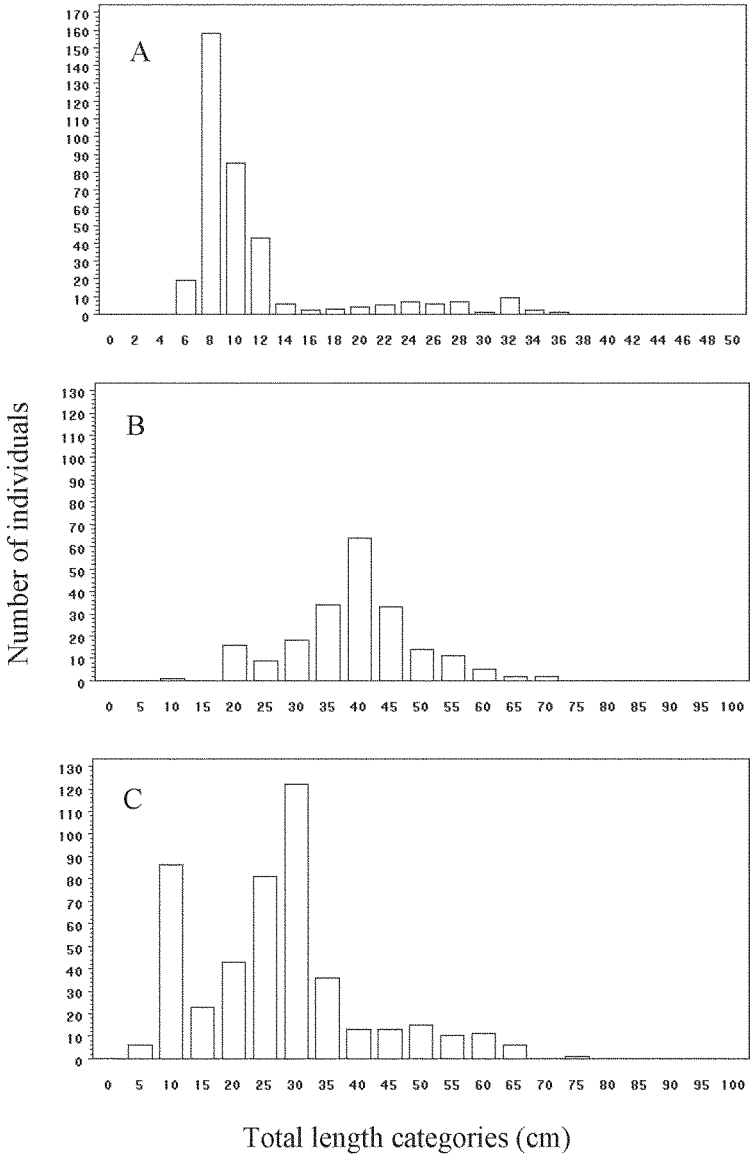

Figure 3-5. Length frequencies for gizzard shad (A; 2 cm length categories), channel catfish (B; 5 cm length categories), and freshwater drum (C; 5 cm length categories) collected from Belleville pool during February 2002 through March 2003.

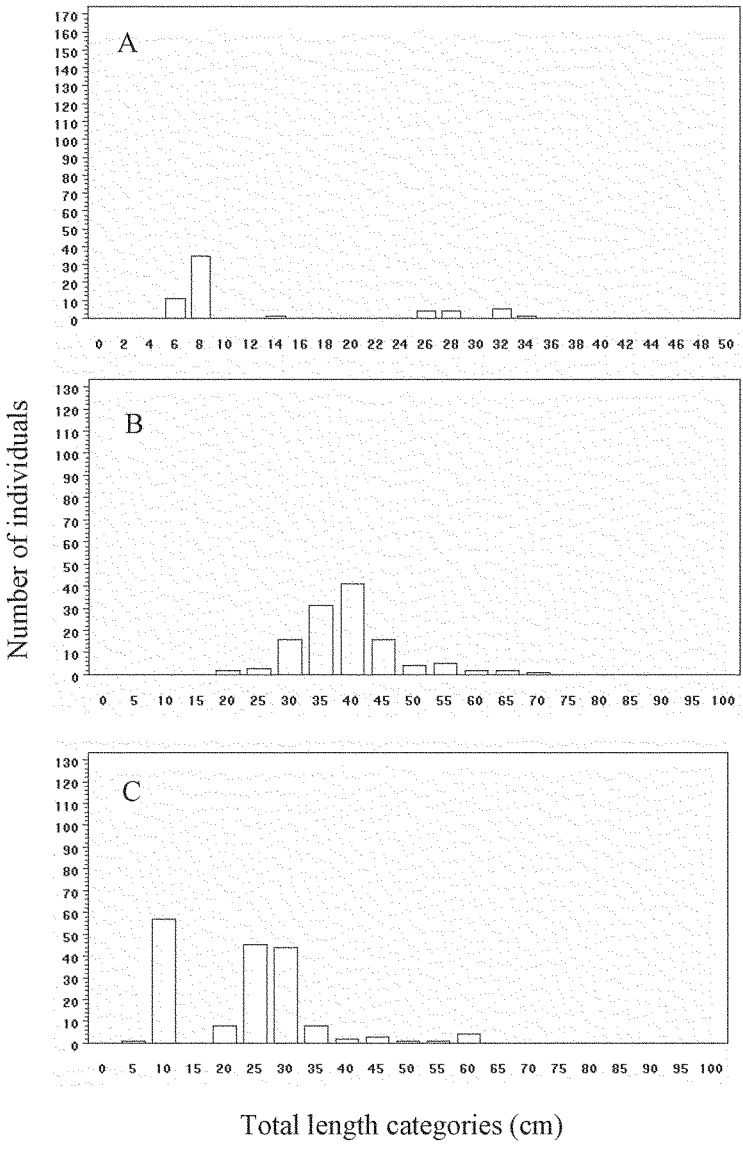

Figure 3-6. Length frequencies for gizzard shad (A; 2 cm length categories), channel catfish (B; 5 cm length categories), and freshwater drum (C; 5 cm length categories) collected from Belleville pool during February 2002 through April 2002.

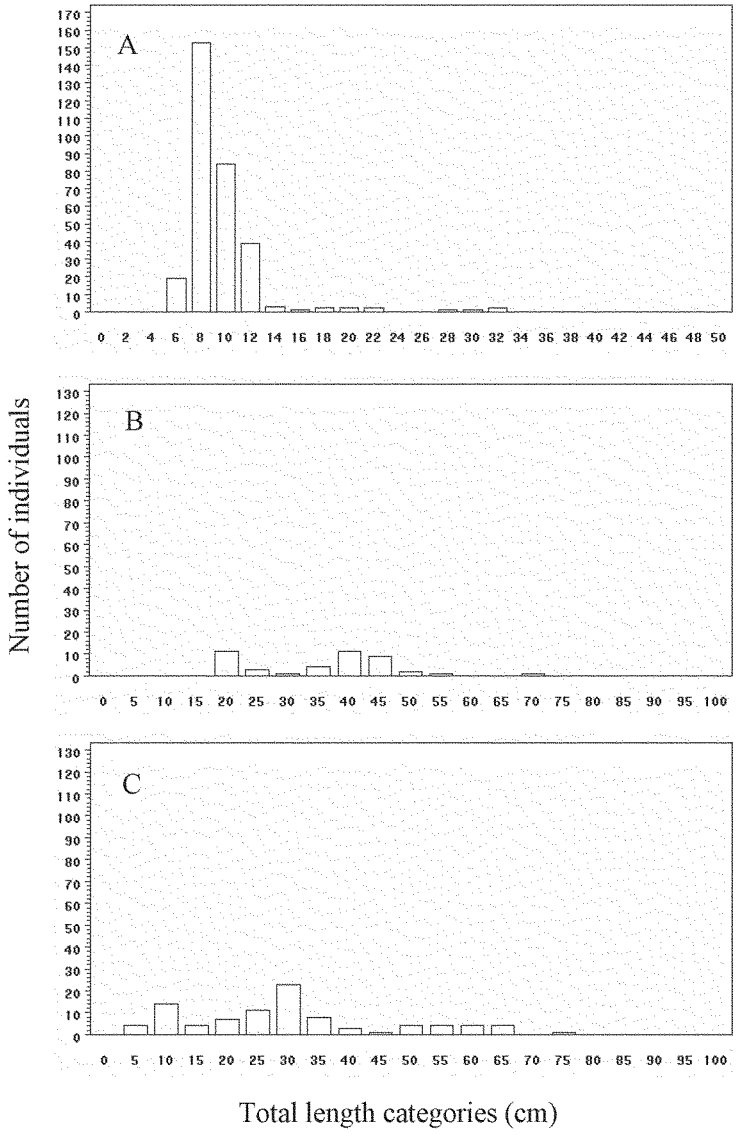

Figure 3-7. Length frequencies for gizzard shad (A; 2 cm length categories), channel catfish (B; 5 cm length categories), and freshwater drum (C; 5 cm length categories) collected from Belleville pool during December 2002 through March 2003.

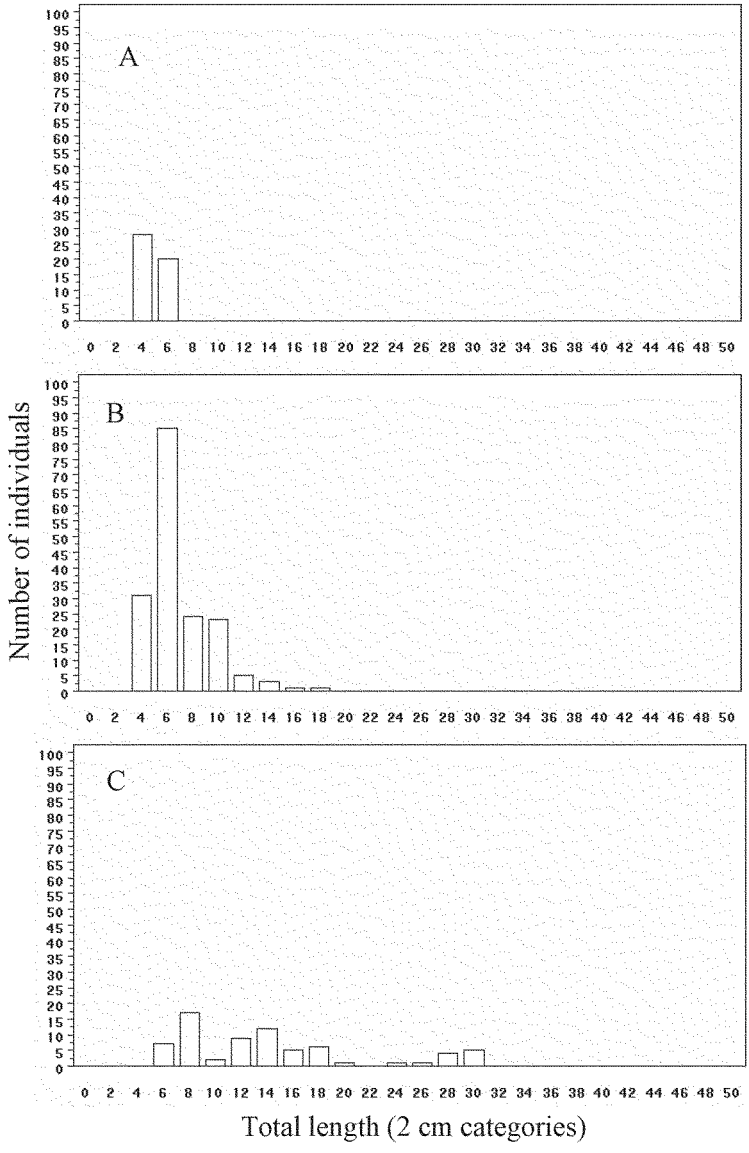

Figure 3-8. Length frequencies for orangespotted sunfish (A), bluegill (B), and white crappie (C) collected from Little Sand Creek embayment during December 2002 through March 2003.

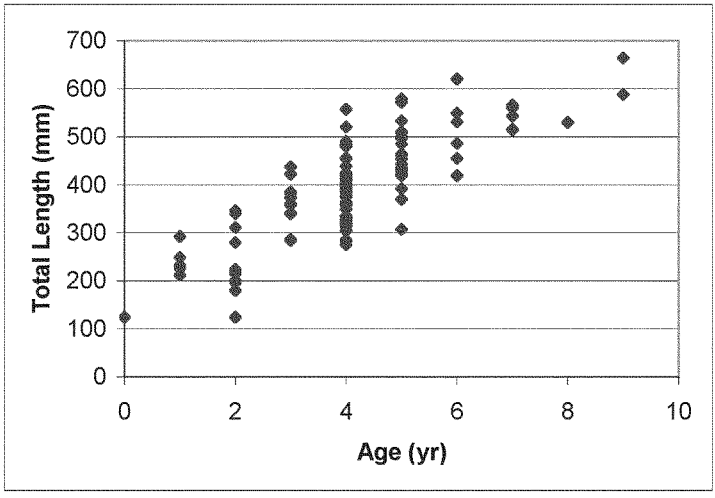

Figure 3-9. Age-length relationship from pectoral spine-based age estimates and total lengths of channel catfish from Ohio River, Belleville Pool.

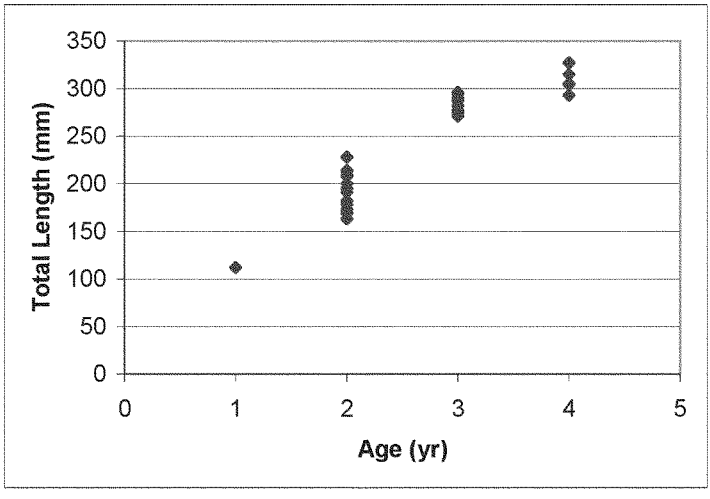

Figure 3-10. Age-length relationship from otolith-based age estimates and total lengths of white bass from Ohio River, Belleville Pool.

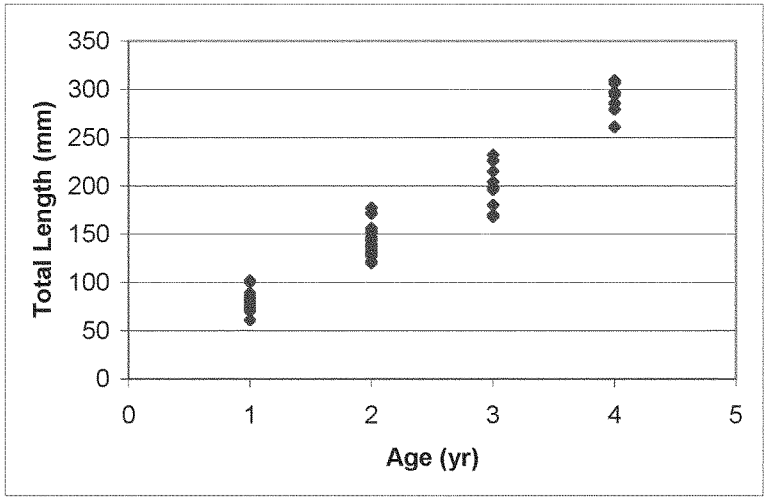

Figure 3-11. Age-length relationship from otolith-based age estimates and total lengths of white crappie from Ohio River, Belleville Pool.

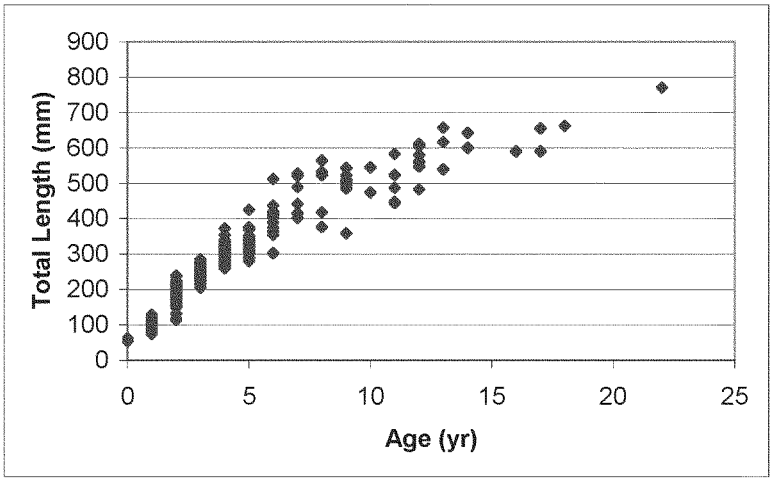

Figure 3-12. Age-length relationship from otolith-based age estimates and total lengths of freshwater drum from Ohio River, Belleville Pool.

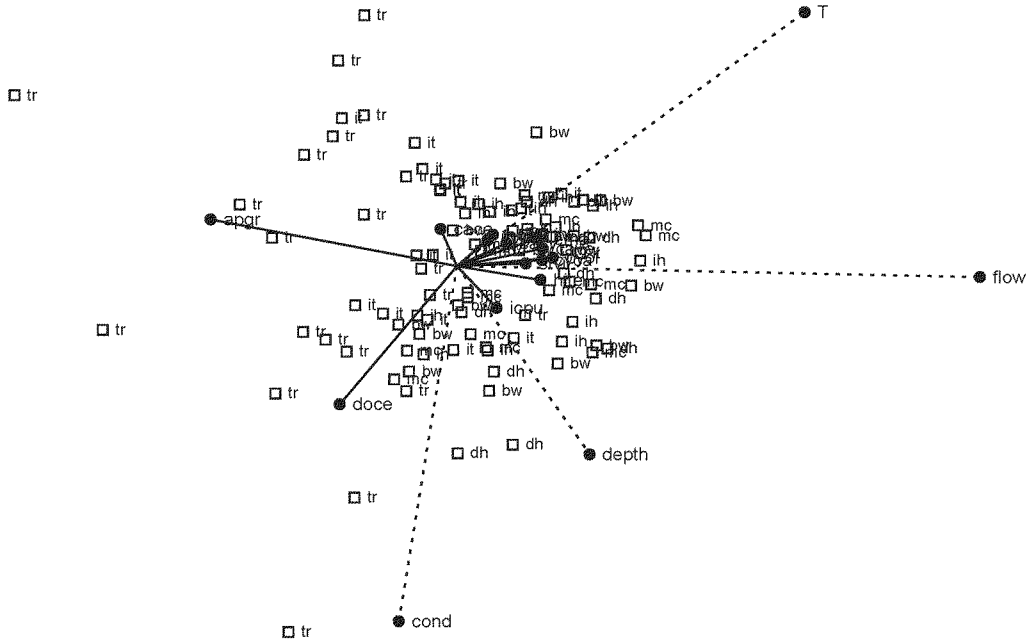

Figure 3-13. Triplot from canonical correspondence analysis (CCA) of species abundance, sites, and abiotic variables from 16 February – 7 April 2002. Sites are abbreviated as tr (tributary), bw (backwater), mc (main channel), ih (island head), it (island tail), and dh (deep hole). Abiotic variables are depth, specific conductivity (cond), temperature (T), and water velocity (flow). Species are denoted as the first two letters of the genus and specific epithet, e.g., freshwater drum (apgr), gizzard shad (doce) and channel catfish (icpu).

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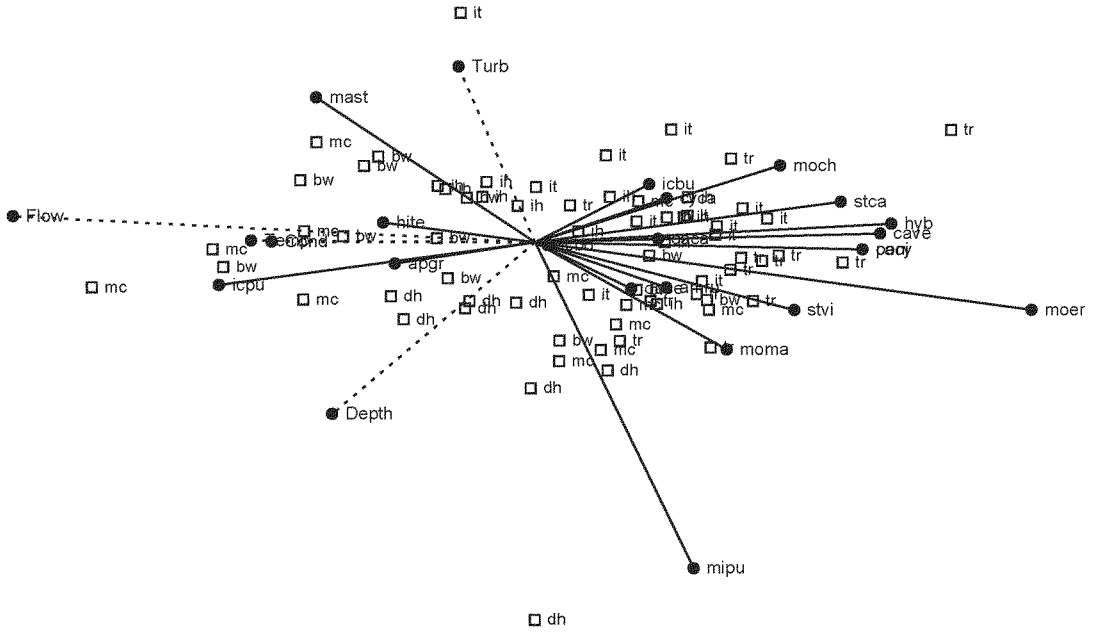

Figure 3-14. Triplot from canonical correspondence analysis (CCA) of species abundance, sites, and abiotic variables from December 2002 and January 2003. Sites are abbreviated as tr (tributary), bw (backwater), mc (main channel), ih (island head), it (island tail), and dh (deep hole). Abiotic variables are depth, specific conductivity (cond), temperature (Temp), turbidity (turb), and water velocity (flow). Species are denoted as the first two letters of the genus and specific epithet, e.g., freshwater drum (apgr), gizzard shad (doce) and channel catfish (icpu).

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APPENDIX I

WINTER HABITAT USE OF FISHES IN THE OHIO RIVER

Benjamin Ernst Lenz

Thesis submitted to the
Davis College of Agriculture, Forestry, and Consumer Science
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in partial fulfillment of the requirements
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Master of Science
in
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ABSTRACT

Winter Habitat Use of Fishes in the Ohio River

Benjamin Ernst Lenz

Winter is a critical period during which fishes may suffer increased mortality. To identify the habitats that fishes use in large rivers during winter conditions, we electrofished six habitat types in the Belleville Pool, Ohio River. We collected the greatest diversity and numbers of fishes in low-velocity tributary confluences when water temperatures were > 4 °C. When water temperatures were < 4 °C, certain species were collected in greater abundance in faster-velocity main channel and back channel habitats while other species continued to associate with lower flows in tributary mouths. Differing habitat use between species obscures broad generalizations about when and how fishes use overwintering refuges.

In an additional habitat sampled, an embayment, 85% of all fishes collected were juveniles. Centrarchids, rarely collected in the mainstem portion of the river, were one of the dominant fishes collected in the embayment. Protecting large river embayments may prove important for managing recreational sunfish fisheries.

Channel catfish, *Ictalurus punctatus*, and freshwater drum, *Aplodinotus grunniens*, the most abundant fishes collected in the Belleville Pool, exhibited growth comparable to other populations in temperate large rivers in eastern North America. Conversely, white bass, *Morone chrysops*, growth was slower compared to other populations, possibly explaining why none of the white bass individuals collected were harvestable size. Population growth and the probability of survival of all fishes may

increase by protecting and enhancing tributary and embayment habitats in large rivers during winter.

Dedicated to my wife Carmen

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To those of you who helped me during the cold months of the year, John Howell, Kim Bjorgo, Gerry Balmert, Dave Wellman, Liz Osier, Jeremy Webster, Chris Nelson, Roy Martin, Dr. Stuart Welsh, Jon Niles, Elsa Lenz, Carmen Crisostomo-Lenz, and Jen Titus, when most others were warm and cozy, I thank you. To John Howell, whose patience proved worthy in crafting a sturdy vessel, I thank you. To my wife, Carmen, who suffered my absence, I thank you. To my mentors, Dr. Stuart Welsh, Dr. Kyle Hartman, and Dr. Alan Temple, I thank you. To George Seidel and Dr. John Sweka, for their statistical prowess, I thank you. To Dr. Pat Mazik, for her leadership, I thank you. To Becky Nestor, for her administrative help, I thank you. To the West Virginia Department of Natural Resources and the United States Army Corps of Engineers for their financial support of this project, I thank you. Last but not least, to Gary Batton for his ever-present humor and allowing us access to what we needed at the Bass Shack, I thank you.

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Chapter 1. Introduction to Winter Habitat Use of Fishes in Large Rivers, Juvenile Mortality during Winter, and the Use of Age and Growth Information in Assessing the Condition of Sport Fisheries.

Overview

This manuscript attempts to define which habitats large river fishes use to survive during winter. We identify the specific abiotic conditions existing in habitats fishes use during winter in the upper Ohio River. Chapter 2 of this manuscript discusses the results from the winter habitat study of the mainstem portion of the Ohio River. Chapter 3 reveals the use of embayments by juvenile fishes during winter in the upper Ohio River. Lastly, Chapter 4 summarizes the results from the age and growth study of three popular game fishes collected during the winter habitat study.

Winter survival of fishes in large rivers

Winter is a critical period during which freshwater fishes suffer increased mortality (Hubbs and Trautman 1935; Cunjak 1988; Garvey et al. 1998). Young-of-year (YOY) fishes often experience the highest mortality during winter (Toneys and Coble 1979; Ludsin and DeVries 1997; Garvey et al. 1998). Yet, fishes of all ages suffer increased mortality during winter. To increase their probability of survival, fish use certain habitats during winter. Fishes in large rivers are no exception to this rule (Johnson et al. 1998).

In large temperate river systems, extremely low water temperatures during winter coupled with high flows increase mortality rates of fishes (Bodensteiner and Lewis 1992; Lyons 1997). Low levels of dissolved oxygen (D. O.) also increase mortality of fishes, and occur typically during ice-cover of backwater areas (Raibley et al. 1997). Many fishes forage infrequently during cold winter extremes, and select refuges that minimize

energy depletion (Crawshaw 1984; Carlson 1992). Fishes often increase fat-reserves before winter; hence, reducing mortality associated with energy depletion (Fullerton et al. 2000). However, energy reserves may not suffice given long winters or energy expenditures due to disturbance, such as variation in river flows or boat traffic (Nielsen et al. 1986). Past research has shown which abiotic conditions large river fishes prefer to minimize mortality during winter.

Abiotic conditions that limit fish survival during winter

Temperature and flow

During winter, riverine fishes select habitats with relatively high temperatures and low flows. Riverine fishes overwinter in velocity shelters (Logsdon 1993; Bodensteiner and Lewis 1994; Johnson et al. 1998) and areas with warmer temperatures and lower flows than mainstem river sections, such as off-channel coves, marinas, embayments and industrial warm-water outflows (Sheehan et al. 1990; Knights et al. 1995; Gent et al. 1995; Raibley et al. 1997). Also, backwater areas with relatively warmer temperatures and lower flows provide winter habitats (Bodensteiner and Lewis 1992; Raibley et al. 1997; Sheehan and Rasmussen 1999). By occupying favorable habitats during winter, fishes avoid the stresses of variable flow velocity in the main channel portion of large rivers.

Sheehan et al. (1990) examined temperature and flow requirements for several fishes common in the Ohio River, such as gizzard shad, *Dorosoma cepedianum*, channel catfish, *Ictalurus punctatus*, and freshwater drum, *Aplodinotus grunniens*. Gizzard shad, channel catfish, and freshwater drum occupy relatively low velocity areas during winter (Heese and Newcomb 1982; Newcomb 1989; Sheehan et al 1990; Logsdon 1993;

Bodensteiner and Lewis 1994). Gizzard shad are vulnerable to winter die-offs during low water temperatures (Miller 1960). Some fishes experiencing extreme low temperatures suffer cold shock (Cichra et al. 1982). These fish lose their ability to maintain their position in a preferred habitat and can be swept downstream to open channel habitats, reducing their chances of survival (Sheehan et al.1990; Bodensteiner and Lewis 1994). Sheehan et al. (1990) reported temperature preferences of > 4 °C for many species in large rivers, such as green sunfish, *Lepomis cyanellus*, bluegill, *Lepomis macrochirus*, and freshwater drum. Some species, such as channel catfish, black crappie, *Pomoxis nigromaculatus*, and walleye, *Stizostedion vitreum*, can maintain swimming abilities at temperatures < 4 °C (Sheehan et al. 1990). Temperature and flow preferences during winter and swimming abilities during low temperatures are unknown for most riverine fishes.

Dissolved oxygen

Abiotic factors other than water temperature and flow velocity can influence the suitability of winter habitats. Backwater areas can become anoxic and unsuitable as overwintering areas (Bodensteiner and Lewis 1992; Knights et al. 1995; Johnson et al. 1998). Low D. O. levels can result in fish die-offs when backwater areas become isolated from the main channel during low water levels in winter (Raibley et al. 1997). In the West Virginia section of the Ohio River, dissolved oxygen is reduced by water pollution near cities, but normally remains above critical levels (Pearson and Krumholz 1984). In the upper Ohio River, the availability and quality of backwater habitat typical of larger rivers such as the Missouri and Mississippi is limited and largely unavailable for fishes. The steep topography of the riparian zone restricts lateral movement of waters outside of

the main channel. Embayments are the habitat type in the upper Ohio River most similar to lower elevation large river backwaters.

Habitats available to fishes in the upper Ohio River during winter

The abiotic conditions of a particular habitat type may make them unsuitable for use by fishes during winter. As stated above, extreme and varying conditions during winter can increase mortality in fishes. To survive, fishes must choose habitats that offer refuge from the extreme conditions of winter. Habitats available to fishes during winter vary in their physical and chemical characteristics. A combination of physiochemical conditions, such as low-flow velocities and warmer temperatures, may offer the best refuge to overwintering fishes, yet these conditions can vary temporally, forcing fishes to use more than one specific habitat during winter.

Nine habitat types classified as main channel, deep hole, back channel, island head, island tail, tributary, wing dam, embayment, and tailwater are available for sampling in the upper Ohio River. Vallazza et al. (1994) and Cray (1999) discussed similar habitats, and our classification scheme is further described below. Main channel habitats are the open water portion of the river used as commercial navigation routes, and typically have shallow near-shore areas and deeper mid-channel sections. Deep hole habitats are relatively deep areas created by dredging or natural scour within main channel or back channel areas. Back channels, island head, and island tail habitats are associated with islands. Back channel habitats are also open waters, but are not typically used for barge navigation and occur between an island and the mainland. Habitats near the upstream and downstream ends of each island are island head and island tail habitats, respectively. Tributary habitats are located, specifically, where the joining waters form a

confluence with the mainstem of the Ohio River. Wing dams (and other artificial flow barriers) create near-shore habitats with low water velocities. Tailwater habitats are the open often-turbulent water immediately below a dam. Embayment habitats are shallow bay-like areas connected to the main channel by a tributary or artificial channel.

Juvenile survival during winter

Survival probability of fishes during winter often increases with body size (Hubbs and Trautman 1935; Cunjak 1988). Juvenile and YOY (young-of-year) individuals suffer increased mortality during winter compared to larger individuals (Toneys and Coble 1979; Ludsin and Devries 1997; Garvey et al 1998). Due to the higher loss of young individuals, winter is a critical period for recruitment into a population (Oliver et al. 1979; Toneys and Coble 1979; Miranda and Hubbard 1994). Limiting exposure to severe winter conditions allows fishes to persist through winter. Juvenile fishes should occupy habitats that are favorable for increasing the probability of survival during winter.

Embayments

Embayment habitats offer critical overwintering refuge for fishes of all ages in large river systems. Embayments are shallow bay-like areas connected to the main channel by a tributary or artificial channel. Backwaters are similar in morphology and function as embayments, but embayments receive input (water, sediment, and aquatic organisms) from both associated tributaries and the riverine system. Backwaters only receive input from their associated river (Cray 1999). Similar to backwaters, embayments offer relatively high temperatures and low flows during winter. These velocity shelters are favorable for overwintering riverine fishes (Logsdon 1993; Bodensteiner and Lewis 1994; Johnson et al. 1998). The warmer temperatures and lower

flows of embayments are often more benign than mainstem river conditions, offering fishes a refuge to escape the harsh conditions of winter (Sheehan et al. 1990, Knights et al. 1995, Gent et al. 1995; Raibley et al. 1997). These favorable conditions in embayments are optimal for overwintering fishes, especially juveniles, since they are most likely to suffer increased mortality during winter.

Importance of age and growth information about sport fisheries

Fish length-at-age estimates are important information used to assess the status of a fishery. The age of a fish can be determined in many ways. Bony parts of the fish such as otoliths, pectoral spines, and vertebrae can all be sectioned (cut) and, by simply counting the growth rings of the section, the reader can estimate the age of an individual. Regardless of the method used to determine ages of fishes, the information gathered yields important insight into age-related growth rates and the relative numbers of juvenile and mature fish in a population (DeVries and Frie 1996). The average size and size variation at different ages over several years can be used to determine growth patterns of a fish population over time or compare it with other populations. Changes in these measurements can be normal or may reflect unsuitable environmental conditions.

Fishery managers also use length and weight data as another method of assessing population condition. The sizes of individuals in a population also reflect growth rates. Knowing the abundance of certain sizes of fishes is important for evaluating the ability of a recreational fishery to support exploitation (Anderson and Neumann 1996). Harvest of recreational fisheries is often regulated by size limits. If few legal-sized individuals are available for harvest, it may be due to unfavorable conditions, which come in many forms (overharvest, pollution, competition for limited resources, overabundance, and more). If

unhealthy conditions persist, fishery managers implement plans to improve the status of a fishery to make it viable for harvest. Without age and growth information, fishery managers would have difficulty in determining the status of sport fish populations.

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Chapter 2. Winter Habitat Use by Fishes in a Large River

Abstract

Winter is a critical period during which fishes suffer increased mortality. In order to identify the abiotic conditions large river fish communities use during winter, we electrofished six habitat types in the Belleville Pool, Ohio River. We collected the greatest diversity and abundance of fishes in low-velocity tributary confluences. When water temperatures were < 4 °C, certain species were collected in greater abundance in faster-velocity main channel and back channel habitats. The lack of temperatures > 4 °C may have left fishes susceptible to current velocity, carrying them out of tributaries into channel habitats. Not all species responded to decreasing water temperatures in the same manner. CCA (canonical correspondence analysis) results showed some species continued to associate with low-velocity tributaries at low temperatures. Species-specific responses to winter conditions may obscure broad generalizations about when and how riverine fishes use overwintering refuges. We recommend that protection and enhancement of tributary habitats can increase the probability of survival of fishes in large rivers during winter.

Introduction

Physiochemical tolerances of fishes influence range distributions and habitat use. In temperate climates, fishes shift habitats in response to seasonal variations in physiochemical factors. During winter conditions, fishes select refuge habitats where physiochemical factors are unlikely to exceed tolerance limits. In large temperate river systems, extremely low water temperatures during winter coupled with high flows

increase mortality rates of fishes (Bodensteiner and Lewis 1992; Lyons 1997). Low levels of dissolved oxygen also increase mortality of fishes, and occur typically during ice-cover of backwater areas (Bodensteiner and Lewis 1992; Knights et al. 1995; Johnson et al. 1998).

Many fishes forage infrequently during cold winter extremes, and select refuges that minimize energy depletion (Crawshaw 1984; Carlson 1992). Fishes often increase fat-reserves before winter; hence, reducing mortality associated with energy depletion (Fullerton et al. 2000). However, energy reserves may not suffice given long winters or energy expenditures due to disturbance, such as variation in river flows or boat traffic (Nielsen et al. 1986).

During winter, riverine fishes select habitats with relatively high temperatures and low flows that offer velocity shelters (Logsdon 1993; Bodensteiner and Lewis 1994; Johnson et al. 1998). These conditions have been found in areas other than mainstem river sections, such as off-channel coves, marinas, embayments and industrial warm-water outflows (Sheehan et al. 1994; Gent et al. 1995: Knights et al. 1995; Raibley et al. 1997). Also, backwater areas with relatively warmer temperatures and lower flows provide winter refuge habitats (Bodensteiner and Lewis 1992; Raibley et al. 1997; Sheehan and Rasmussen 1999).

Sheehan et al. (1990) examined temperature and flow requirements in the laboratory for several fishes common in the Ohio River, such as gizzard shad, *Dorosoma cepedianum*, channel catfish, *Ictalurus punctatus*, and freshwater drum, *Aplodinotus grunniens*. These three fishes occupy relatively low velocity areas during winter (Heese and Newcomb 1982; Newcomb 1989; Sheehan et al. 1990; Logsdon 1993; Bodensteiner

and Lewis 1994). Gizzard shad are vulnerable to winter die-offs during low water temperatures (Miller 1960). Sheehan et al. (1990) also reported temperature preferences of > 4 °C for many species in large rivers, such as green sunfish, *Lepomis cyanellus*, bluegill, *Lepomis macrochirus*, and freshwater drum. Some species, such as channel catfish, black crappie, *Pomoxis nigromaculatus*, and walleye, *Stizostedion vitreum*, can maintain swimming abilities at temperatures < 4 °C (Sheehan et al. 1990). However, temperature, flow preferences, and swimming abilities during low temperatures are unknown for most riverine fishes.

To quantify winter habitats of fishes in large rivers, we sampled the Belleville Pool of the Ohio River during the winter months of 2002 and 2003. Previous research is primarily limited to *in vitro* analysis of simulated winter abiotic conditions preferred by large river fishes. Our goal was to analyze *in situ* winter habitat use by fishes in large rivers. Thus, our main objective was to determine abiotic habitat characteristics associated with fish habitat use. We attempted to do this by examining species/habitat associations among main channel, tributary mouth, back channel, head of island, tail of island, and deep hole habitats during winter. Through an understanding of overwintering areas, we hope to provide resource managers with knowledge needed to reduce winter mortality of fishes by protecting and enhancing important habitats.

Methods

Study site

The Belleville Pool of the Ohio River, created by Belleville Lock and Dam (rkm 328.1), extends upstream to Willow Island Lock and Dam (rkm 260.2). The 67.9 km pool averages 404.5 m wide, 7.3 m deep, and comprises 2850 ha of surface area

(ORSANCO 1994). The deepest section of the pool (15 m) lies directly upstream of Belleville Lock and Dam. A navigation channel (3.7 m deep) is maintained for commercial barge traffic by the United States Army Corps of Engineers (USACE) (ORSANCO 1994). Two other large rivers, the Muskingum River in Ohio, and the Little Kanawha River in West Virginia are navigable tributaries of the Ohio River within the Belleville Pool. The riparian zone is a mixture of hardwood forests, urban and industrial frameworks, and agricultural settings. Most large floodplains near Belleville Pool are heavily urbanized. The two largest population centers along Belleville Pool are Parkersburg, WV (confluence of the Little Kanawha and Ohio rivers) and Marietta, OH (junction of Muskingum and Ohio rivers).

Habitat classification

For the purpose of defining habitat use by overwintering fishes, we classified six habitat types in the Belleville Pool: main channel, deep hole, back channel, island head, island tail, and tributary confluence (see Vallazza et al. 1994, Cray 1999). Main channel habitats are used as commercial navigation routes, and typically have shallow near-shore areas and deeper mid-channel sections. Deep hole habitats (> 8 m in depth) result from dredging or natural scour within main channel or back channel areas. Back channel, island head, and island tail habitats are associated with islands. Back channel habitats are not typically used for commercial navigation and occur between an island and the mainland. The waters immediately adjacent to the upstream and downstream ends of each island are island head and island tail habitats, respectively. Tributary habitats are located, specifically, where the joining waters form a confluence with the mainstem of the Ohio River.

Habitat selection

To evaluate winter habitat selection by fishes within the Ohio River, we sampled six sites in six habitat categories on six different occasions. Main channel and tributary sites were selected in a constrained random fashion according to their relative abundance in the upper and lower half of the Belleville Pool. We chose six of the seven island habitats located in the Belleville Pool. Island size (measured in length) differed among Blennerhasset (6.4 km), Halfway (1.6 km), Newberry (0.4 km), Marietta (4.8 km), Muskingum (3.2 km), and Neal (2.4 km) Islands, but sample areas within back channel, head, and tail habitats were similar among islands. Depths of main channel and back channel sites ranged from 3 to 8 m, and included near-shore and mid-channel transects. Tributary habitats were 2 to 9 m deep, and included near-shore areas and deeper scour holes. Depths of deep hole habitats ranged from 8 to 14 m, and those of island head and tail habitats ranged from 2 to 6 m.

Data collection

We sampled fish at the habitat sites during six periods (February 16 – 22, 2002, March 9 - 25, 2002, April 4 - 7, 2002, December 12 - 17, 2002, January 10 -19, 2003, and March 1 -17, 2003). At each site, we sampled fishes with a variable-depth AC electrofishing boat for water depths of 2-15 meters (Grunwald 1983, Newcomb 1989). Three weighted electrodes (2 m sections of 1.25 inch diameter corrugated conduit) were lowered to near the river bottom over a boom connected to the bow. The desired output of the Honda 5 kilowatt 3-phase AC generator, monitored by clip-on gauges, was above 7 Irms, and typically 9-10 Irms while collecting fish. One, two, or three transects were

electrofished, (depending on the amount of available habitat at a site), in the downstream direction of the river current lasting up to 10-minutes (peddle time) for each transect. During peddle time, the boat (with bow upstream) drifted with the river current. This maintained electrodes near the river bottom, but caused longer transects during higher flows. In habitats with a wide range of depths such as back and main channel habitats, the three transects represented shallow and intermediate depths near each shore and deep areas in mid-channel. Peddle time and number of transects varied with habitat availability at each site. During and after peddle time, fishes were netted from a chase boat or the electrofishing boat. Collected fishes were identified to species, counted, measured (nearest mm total length, TL), and weighed. Large fishes (over 1 kg) were weighed to the nearest 25 g with a Pesola spring scale (5 kg maximum). Smaller fishes (less than 1 kg) were weighed to the nearest 1g with a Homs spring dial scale (1 kg maximum).

Abiotic conditions were measured at each site to further characterize habitat types. After electrofishing at a site, we measured specific conductivity, dissolved oxygen (DO), pH, and temperature at 1-m depth intervals (YSI 6820 meter or Hydrolab Surveyor 4), and estimated surface flow velocity (Marsh-McBirney Flowmate). We estimated turbidity near surface (secchi disk), and at 1 m depth intervals (YSI 6820 meter) during the second winter sampling (December 2002 to March 2003). We used Tidbit temperature loggers to record water temperature at three back channel and three main channel sites at depths between 1 and 2 m during both winter samples.

Statistical analyses

To characterize the six habitat categories, the abiotic variables were averaged by site and sample period. First, the profile values for each abiotic variable, from surface to near bottom were averaged as a single value for each site (except flow and secchi, which were single values). Second, the six site average values for each abiotic variable were averaged as a single value for each habitat type for each of the six periods (e.g., all average temperature values from tributary sites during December 12-17, 2002 were averaged as a single value). Third, the abiotic values from the three sample periods were averaged as a single value for each habitat category for both of the winter samples (February – April, 2002 and December, 2002 – March, 2003). Finally, standard deviations of the averaged abiotic variables were also calculated.

To determine which habitats particular species of fish used at critical low temperatures, we first calculated the proportion of the total catch for each species collected at average temperature values > 4 °C, 3 < 4 °C, and < 3 °C in each habitat category. These temperature values stem from the laboratory findings of Sheehan et al. (1990) suggesting < 4 °C is the critical water temperature when many riverine fishes lose their swimming ability and are unable to maintain their position in the water column. Second, we calculated the percentage of the total catch at each temperature range for the five most numerous fishes at each temperature range separately. All other less numerous fishes were calculated as a single group. Lastly, we counted the number of species collected in each habitat category.

We used canonical correspondence analysis (CCA) to explore relationships between species and abiotic variables. Canonical correspondence analysis, a constrained

ordination approach, allowed concurrent analysis of species abundance, site, and environmental (abiotic) data (ter Braak 1995). A square root transformation of abundance data minimized affects of a few high abundance values (McGarigal et al. 2000). We conducted CCAs with data from each winter sample separately using an Excel macro (Eric Smith, Virginia Polytechnic Institute and State University). A significant high water event during March 2003 (see Figure 2b) interrupted our data collection and forced us to finish over a much greater length of time than the previous two sample periods. For this reason, the CCA for the second winter sample only represents data collected from December 12, 2002 through January 19, 2003.

Results

Tributary habitats represented important overwintering habitats for large river fishes. Tributary habitats consistently had the lowest average flow velocity (mode of 0.1 m/s) during all sample periods (Table 1). Low flow velocities likely contributed to the relatively high numbers of fishes caught at tributaries. Fifty-eight percent of the total individuals collected during both winter samples were from tributaries. More individuals were collected in tributaries during the warmer first winter sample (87 % of the total individuals from this sample) than the colder second winter sample (Table 1). Thirty-nine percent of the total individuals from the second winter sample were collected in tributaries.

Species presence and abundance in both back and main channel habitats increased during colder water temperatures. Forty-three percent and 14% of all individuals were collected in main channel and back channel habitats, respectively, during the colder winter sample. When sites had an average temperature > 4 °C, more individuals were

collected in tributaries (66 %) than main and back channel sites (30 %) (Figure 1a). At temperatures between 3 and 4 °C, more individuals were still collected at tributaries, but at a reduced proportion compared to main and back channel sites at temperatures > 4 °C (Figure 1b). A shift to a greater proportion of individuals occupying main and back channel sites occurred when water temperatures at all habitat types were < 3 °C (Figure 1c). Sixty-six percent of the individuals were collected at main channel sites, while 31 % were collected at tributary sites at water temperatures < 3 °C.

Freshwater drum was the most abundant species captured, representing 48 % of the total catch from both winter samples. During the warmer first winter, 90% of the freshwater drum individuals were collected from tributaries. Freshwater drum dominated the pattern of shifting from tributary to main channel habitats when water temperatures at all habitat types were < 3 °C (Figure 1). During the colder sample, 37% of the freshwater drum individuals were collected from tributaries, while 50% were collected in main channel sites. Other less numerous species followed a similar pattern.

Channel catfish, the second most abundant species, represented 21% of the total catch from both winter samples. Sixty-three percent of the channel catfish individuals were collected from tributary habitats during the warmer sample. Channel catfish followed a similar yet more pronounced pattern as freshwater drum by shifting to main and back channel habitats when water temperatures at all habitat types were < 4 °C (Figure 1). Fifty-three percent of the channel catfish individuals were collected in tributaries and 43 % in main and back channel habitats at temperatures > 4 °C. At temperatures between 3 and 4 °C, 84 % of the channel catfish individuals were collected

in main and back channel habitats. Likewise, 83 % of all channel catfish individuals were collected in main and back channel sites when temperatures were < 3 °C.

Tributary habitats also had the highest species diversity of all habitat types. A total of 19 species were collected in tributaries, while totals of 14 and 11 species were collected in main channel and back channel habitats, respectively (Figure 3). Even during January 10 –19, 2003, the coldest sampling period (average water temperatures ranged between 2.1 and 3.0 °C; Table 1), tributaries still contained the highest species diversity (N=13). However, most of the species collected in January 2003 were from one site, Bull Creek.

High abundance and species diversity occurred in Bull Creek (a tributary habitat) during both winter samples. During the second winter sample, 75 % of the fish captured in tributaries and 30 % of the total catch from all habitat types were from Bull Creek. Bull Creek had the single greatest total catch of fishes at one site (134 individuals on January 11, 2003) when the water temperature was 3.2 °C (Figure 5 shows a captured sonar image of this event). Interestingly, immediately downstream from Bull Creek, the largest single catch of fishes at a main channel site occurred on the same day.

The CCA results indicate which abiotic conditions correspond with individual species habitat use. The large difference between mean abiotic conditions of the two winter samples, (February 7, 2002 – April 7, 2002 had warmer water temperatures than December 12, 2002 – March 17, 2003; Figure 2 and Table 1), offered a chance to explore individual species differences in habitat use during winter. Because one fish species (freshwater drum) dominated our collections, these exploratory results allowed us to see if other species followed similar patterns of winter habitat use as freshwater drum.

Freshwater drum (# 23 in Figure 4a) corresponded with decreasing flow values and tributary sites during the warmer winter sample. Channel catfish (# 13 in Figure 4a) were weakly linked to increasing water temperatures and the sites that contained them (4 main channel sites and 1 tributary site, Duck Creek on March 24, 2002, when 50 of the 100 fishes collected were channel catfish) during the warmer sample. Only channel catfish weakly correlated with water temperatures during the warmer period, probably due to increased average water temperatures across all habitat types during this time period (Table 1). During the first winter sample, gizzard shad (# 2 in Figure 4a) closely associated with increased conductivity values of some tributary sites. The other species collected during the first sample period corresponded with relatively lower flows and slightly increasing depths. Most of these fishes (9 of the 13 species), however, were collected in negligible abundance from two tributary sites, Bull and Duck Creeks.

Contrary to the warmer sampling period, freshwater drum (# 23 in Figure 4b) corresponded equally (but to a slightly lesser intensity) with channel catfish (# 13 in Figure 4b) to increasing flow velocity, water temperature, and conductivity during the colder sampling period. Mooneye, *Hiodon tergisus*, (#3 in Figure 4b) also closely coincided with increasing values of these same abiotic variables. Main and back channel sites were associated with increasing flow velocity, temperature and conductivity axes. Fourteen of the 20 species were correlated with decreasing values of these three major axes and were associated with tributary sites.

Discussion

Low-velocity tributary habitats contained the highest abundances and diversity of fishes during February 2002 - March 2003 sample sessions. Although other unmeasured

variables may explain fish use of tributary habitats during winter, we believe that low velocity is an important abiotic regulator of winter habitat use. Supporting this conclusion, largemouth bass, *Micropterus salmoides*, in the Hudson River (Carlson 1992), and river carpsucker, *Carpiodes carpio*, and sauger, *Stizostedion canadense*, in the Missouri River (Braaten and Guy 1999) also used tributary confluences during winter. We do not believe that electrofishing sampling efficiency was higher in tributary habitats because ambient conductivities (Reynolds 1996) were similar in all habitats during both years (ranged from 182 – 303 uS/cm) and were close to the standard conductivity of a fish (115 uS/cm) (Miranda and Dolan 2003).

River current velocities may overcome fishes' swimming ability to hold their position in preferred habitats such as tributaries as water temperatures decline below 4 °C. During our coldest sample periods (water temperatures < 4 °C), the catch of several species increased in back channel or main channel habitats, including channel catfish, and freshwater drum (Figure 1). We did not have high catches of fish in back and main channel habitats, except when average water temperatures in low-velocity tributary habitats were < 3 °C. On January 11, 2003, all tributary habitats were < 3 °C, except for Bull Creek (3.2 °C) when the single highest total catch of fishes occurred (Figure 5). It is possible that previous to this sampling date, the high flow conditions and declining water temperatures (Figure 2b) forced fishes to occupy relatively lower-velocity tributary sites like Bull Creek. On January 11, 2003, the declining temperatures may have limited fishes' swimming ability. The minimum amount of flow that existed in Bull Creek on that day may have swept fishes downstream into an eddy current along the main channel shoreline immediately below the mouth of Bull Creek, where they were collected. In the

upper Mississippi River, Bodensteiner and Lewis (1994) documented increased flow velocity coupled with near-freezing water temperature caused freshwater drum to lose equilibrium and become incapacitated, resulting in large numbers of individuals floating downstream with the current.

The lack of sufficiently warmer temperatures may force fishes to occupy main and back channel habitats. Average water temperatures in channel habitats were higher than tributaries during January 2003, yet still below the critical 4 °C (Table 1). Sheehan et al. (1990) reported riverine fishes in laboratory conditions preferred water temperatures > 4 °C. If water temperatures > 4 °C are unavailable, current velocities may overwhelm fishes' swimming ability, sending them downstream where they collect in channel borders. However, the ability to withstand critically low water temperatures may vary between species.

Species-specific responses to winter conditions result in differential habitat use. Physiochemical tolerances vary among fish species (Sheehan et al. 1990), which was evident between our two most abundant species. For example, channel catfish occupied warmer and deeper habitats, while freshwater drum occupied shallower habitats with lower flow velocities during February 16 through April 7, 2002 (Figure 4a). During this time period, freshwater drum appeared less tolerant of higher flow velocities, but used shallower habitats than channel catfish. However, during the coldest months of 2003, freshwater drum occupied warmer and deeper habitats with higher flow velocities, similar to channel catfish (Figure 4b), suggesting a mutual tolerance of physiochemical factors during severe winter conditions. Conversely, other species continued to associate with lower temperatures at low-velocity tributaries (Figure 4b).

Our study was conditional on six habitats, but other overwintering habitats occur in Belleville Pool. We also sampled and found high diversity and abundance of fishes in an embayment, downstream of a wing dam, and within an industrial warm-water outflow, but these habitats (uncommon within Belleville Pool) were not part of our study design. Off-channel coves, marinas, embayments and industrial warm-water outflows have been shown to be valuable overwintering refuges for fishes (Sheehan et al. 1994; Gent et al. 1995; Knights et al. 1995; Raibley et al. 1997). Additional studies of alternative habitats, such as embayments, warm-water outflows, artificial structures, and tailwaters, are needed to further address fish-habitat relationships in large rivers.

In conclusion, our data support tributary confluences as important overwintering sites for fishes in the Belleville Pool, Ohio River. Some fishes, however, shift to main and back channel habitats when temperatures are < 3 °C. If altered or unprotected, the loss of overwintering habitats at tributary mouths could contribute to increased mortality of fishes during winter. Additionally, tributary mouths are susceptible to disturbance from boat and barge traffic, and fishes using these habitats during winter could be displaced. Nielsen (1986) and Sheehan and Rasmussen (1999) suggested detrimental effects of commercial boat traffic on fishes in large rivers. Passage of boats during winter causes turbulence, possibly forcing fish from their overwintering position. Those fishes forced into less suitable conditions may suffer increased mortality. Protecting tributary confluences from further degradation by commercial boat traffic, pollution, sedimentation, and channelization, among others, may increase the probability of survival of fishes in large rivers.

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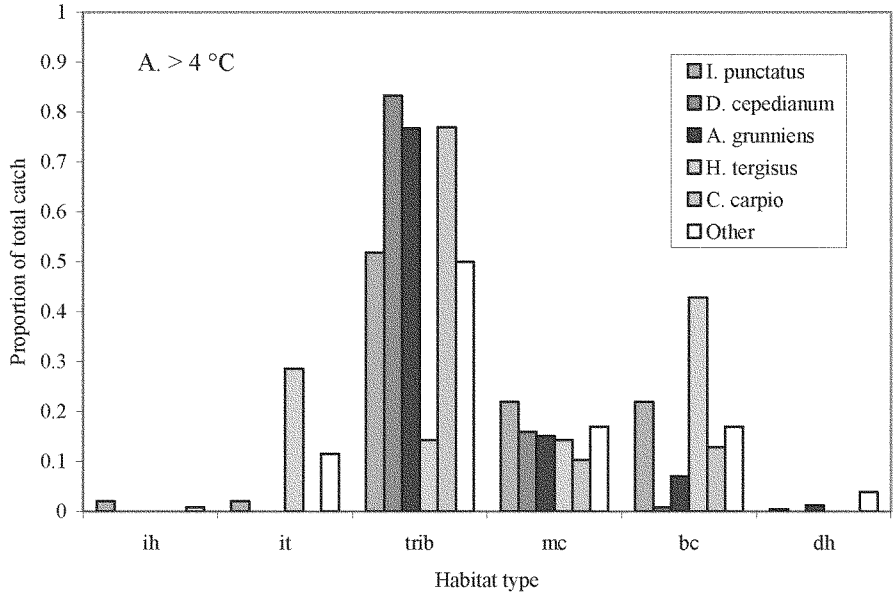
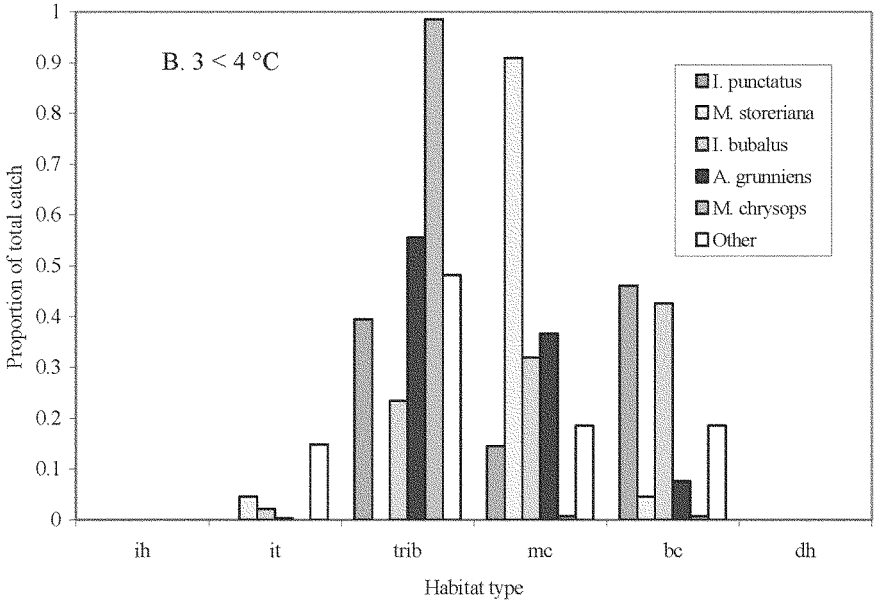
Figures and Tables

Figure 1. The proportion of the total catch of each species among habitat categories. Data are separated by water temperatures > 4 °C (A), 3 < 4 °C (B), and < 3 °C (C) within the Belleville Pool, Ohio River, during February 17 through April 7, 2002 and December 12, 2002 through March 17, 2003. Sites are abbreviated as bc (back channel), dh (deep hole), ih (island head), it (island tail), mc (main channel), and tr (tributary). Fish species are abbreviated as *D. cepedianum* (gizzard shad), *H. tergisus* (mooneye), *M. storeriana* (silver chub), *C. carpio* (river carpsucker), *I. bubalus* (smallmouth buffalo), *I. punctatus* (channel catfish), *M. chrysops* (white bass), *M. saxatilis x chrysops* (hybrid striped bass), and *A. grunniens* (freshwater drum).




B. 3 < 4 °C
Proportion of total catch
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ih
it
trib
mc
bc
dh
Habitat type
I. punctatus
M. storeriana
I. bubalus
A. grunniens
M. chrysops
Other

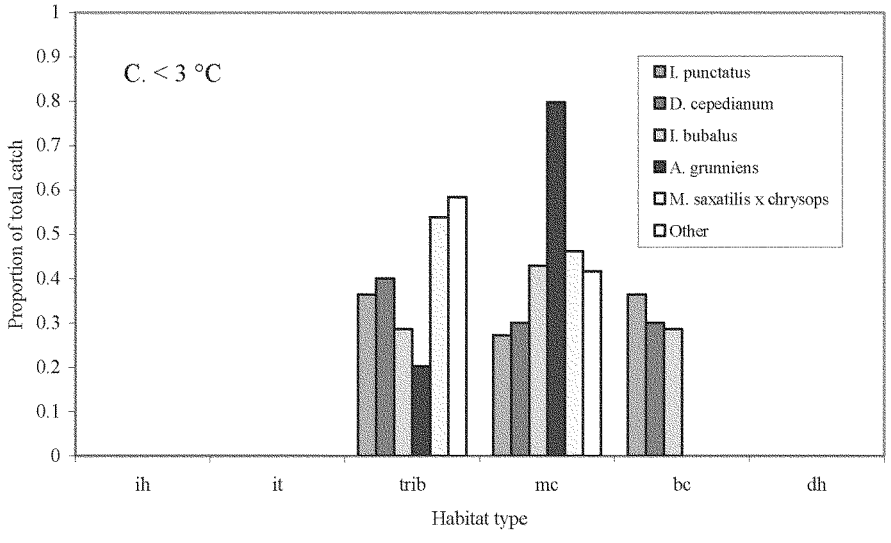
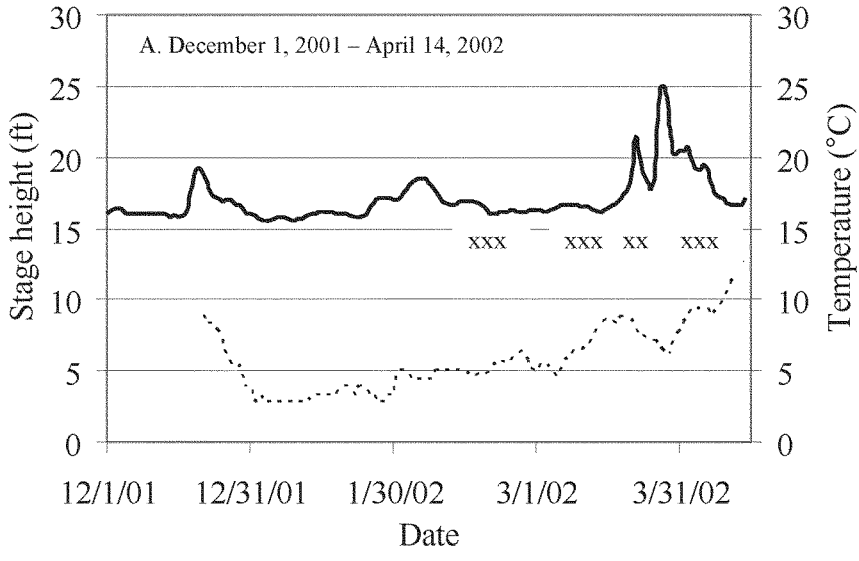

C. < 3 °C
Proportion of total catch
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ih
it
trib
mc
bc
dh
Habitat type
I. punctatus
D. cepedianum
I. bubalus
A. grunniens
M. saxatilis x chrysops
Other

Figure 2. Water temperature (broken line), stage height (solid line), and sampling session dates (x) in Belleville Pool, Ohio River, during December 1, 2001 through April 14, 2002 (A) and December 1, 2002 through April 14, 2003 (B).



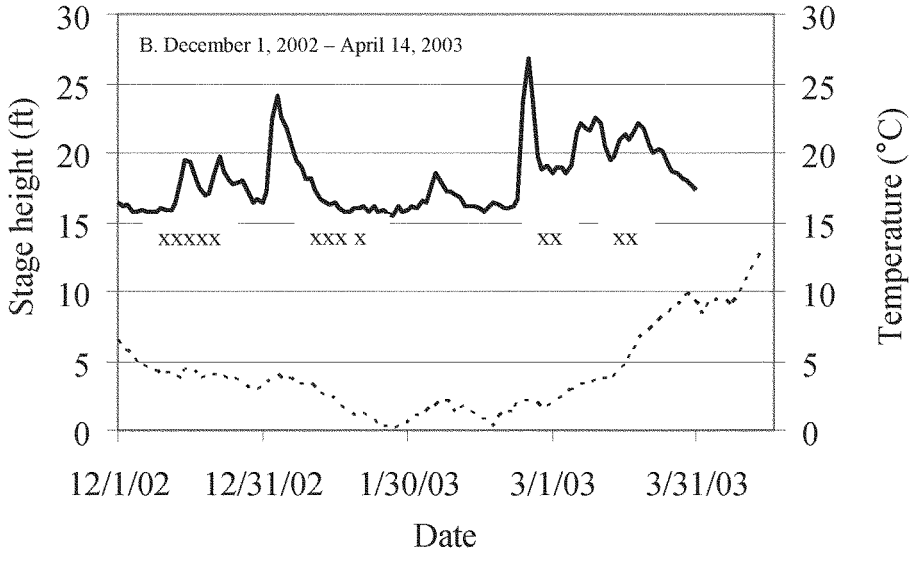

B. December 1, 2002 – April 14, 2003
Stage height (ft)
Temperature (°C)
30
25
20
15
10
5
0
xxxxx
xxx x
xx
xx
12/1/02
12/31/02
1/30/03
3/1/03
3/31/03
Date

Figure 3. The number of species in each habitat category collected in the Belleville Pool during December 1, 2001 through April 14, 2002 and December 1, 2002 through April 14, 2003. Sites are abbreviated as ih (island head), it (island tail), trib (tributary), mc (main channel), bc (back channel), and dh (deep hole).

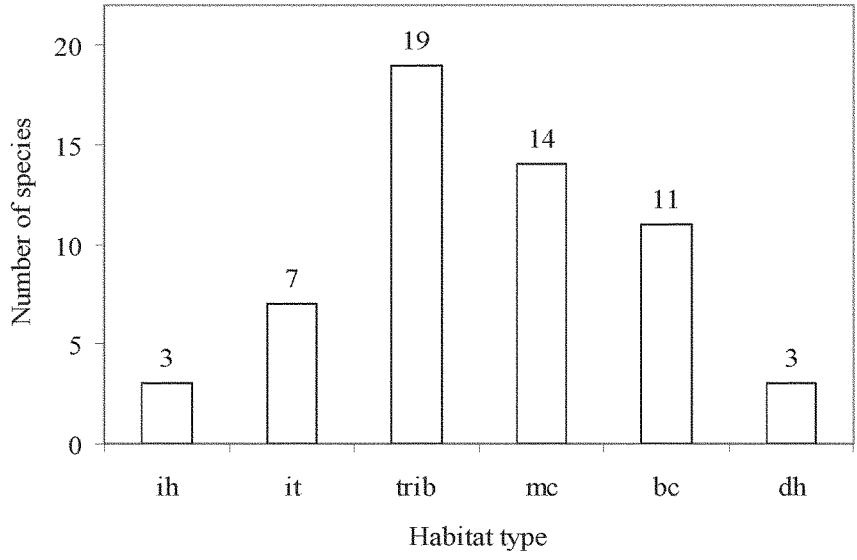
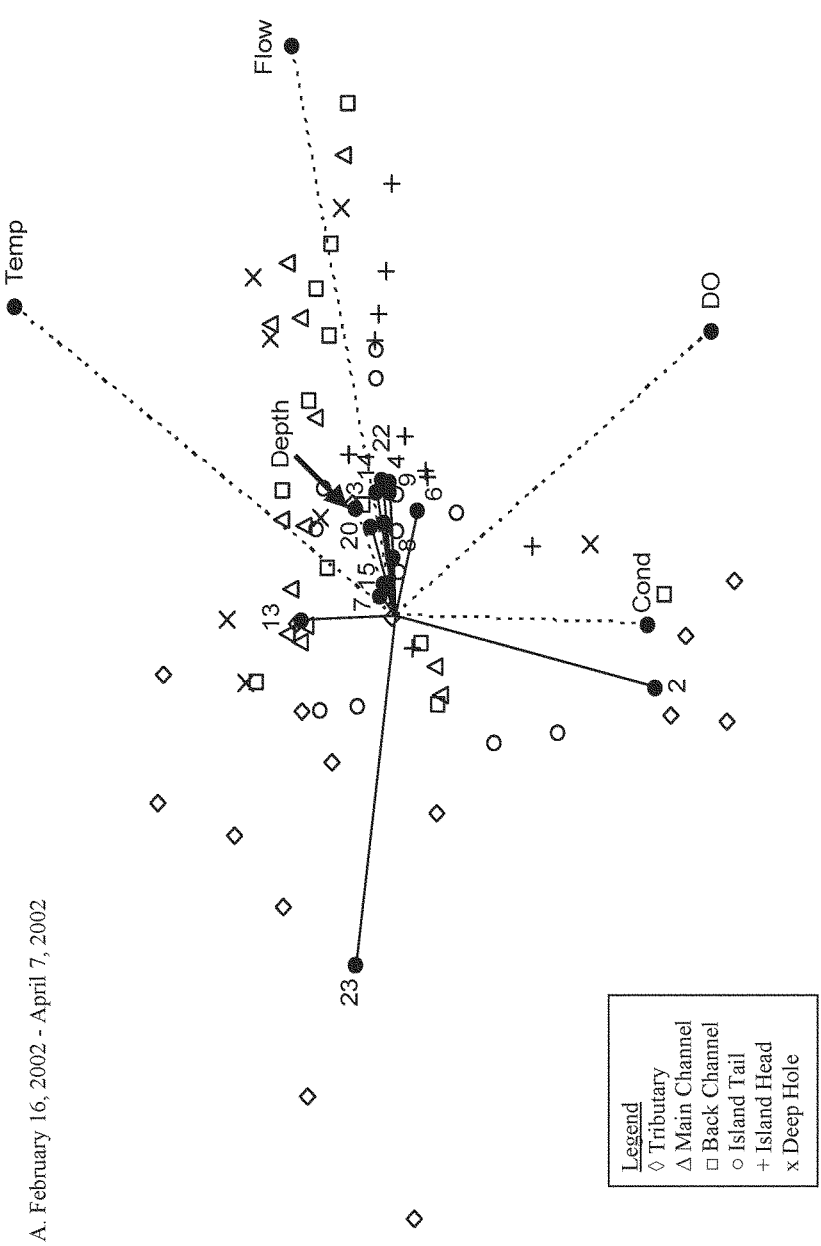


Figure 4. Triplot from canonical correspondence analysis (CCA) of species abundance, sites, and abiotic variables from February 16, 2002 through April 7, 2002 (A) and December 12, 2002 through January 19, 2003 (B) in the Belleville Pool, Ohio River. Sites are symbolized as ◊ (tributary), + (island head), ○ (island tail), □ (back channel), Δ (main channel), and x (deep hole). Abiotic variables are depth, specific conductivity (Cond), temperature (Temp), turbidity (Turb), and water velocity (Flow). Species are numbered as 1) *I. bdellium*, 2) *D. cepedianum*, 3) *H. tergisus*, 4) *Cyprinus carpio*, 5) *M. storeriana*, 6) *N. atherinoides*, 7) *Carpiodes carpio*, 8) *C. cyprinus*, 9) *C. velifer*, 10) *M. erythrurum*, 11) *M. macrolepidotum*, 12) *I. bubalus*, 13) *I. punctatus*, 14) *P. olivaris*, 15) *M. chrysops*, 16) *M. chrysops x saxatilis*, 17) *A. rupestris*, 18) *P. nigromaculatus*, 19) *M. punctatus*, 20) *L. macrochirus*, 21) *S. canadense*, 22) *S. vitreum*, and 23) *A. grunniens*.



A. February 16, 2002 - April 7, 2002

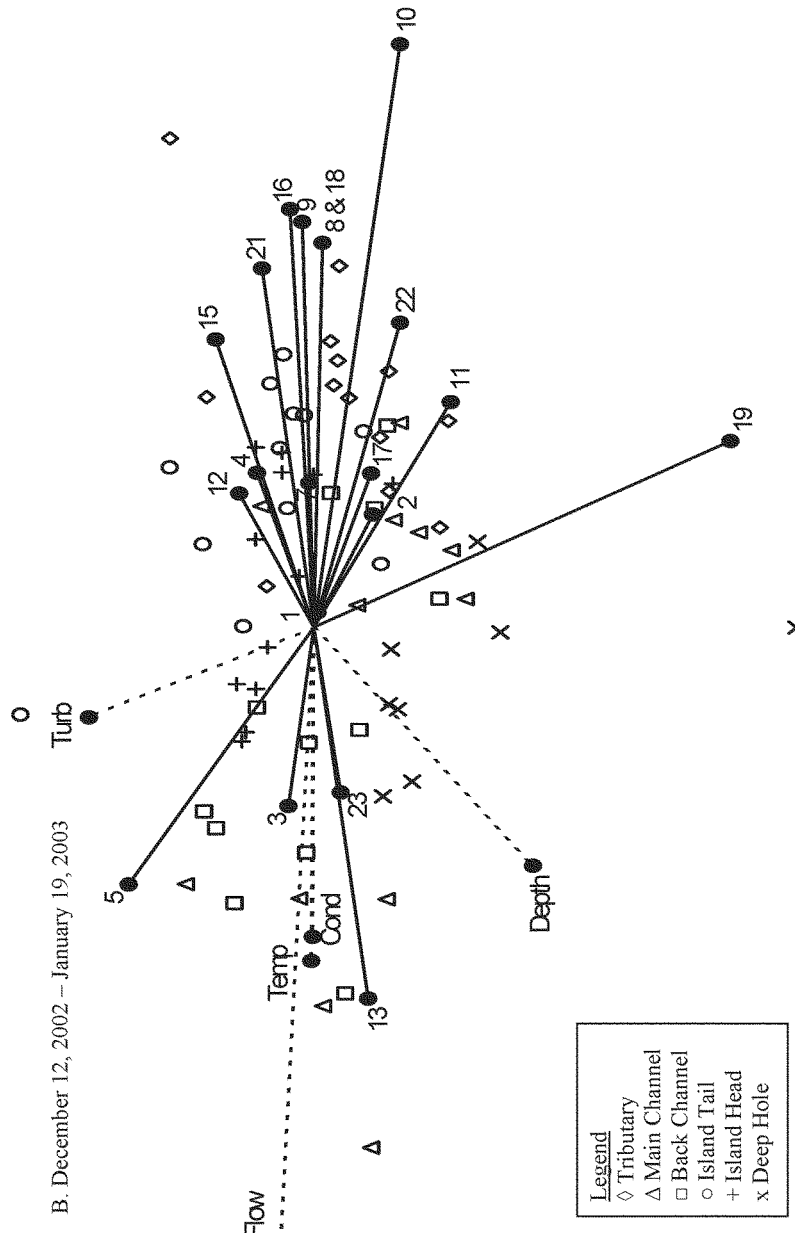

B. December 12, 2002 – January 19, 2003
Turb
Flow
Temp
Cond
Depth
1
2
3
4
5
6
7
8 & 18
9
10
11
12
13
15
16
17
19
21
22
23
Legend
◊ Tributary
Δ Main Channel
□ Back Channel
○ Island Tail
+ Island Head
x Deep Hole

Figure 5. The captured sonar image from Bull Creek on January 11, 2003, when the single highest total catch of fishes occurred. Black streak like blotches are individual fish.

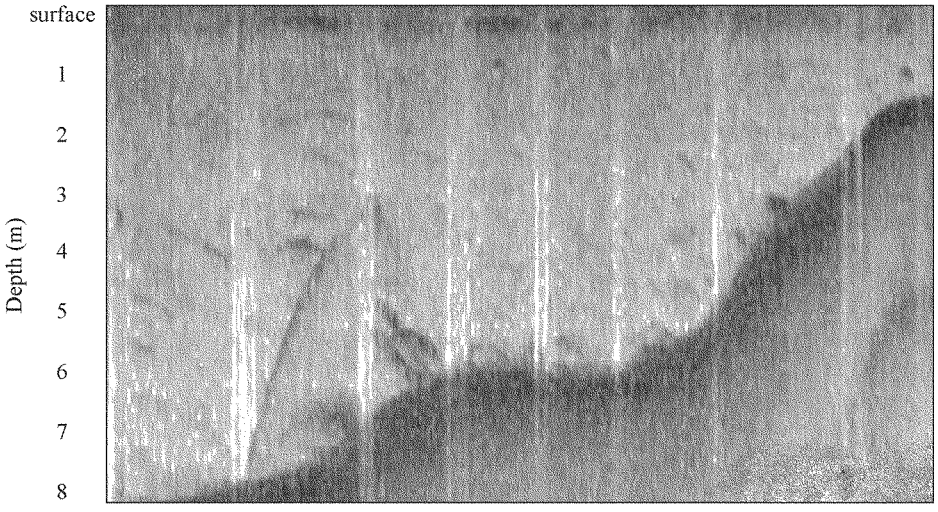


Table 1. Average abiotic conditions of all sites in six habitat types during six different sampling periods between February 16 through April 7, 2002 and December 12, 2002 through March 17, 2003 in the Belleville Pool, Ohio River. Standard deviations are in parentheses. Habitat types and abiotic variables with no values were not sampled during February 16 - 22, 2002 and the deep hole category with no standard deviation values only had one sample site during this period.

Date	Habitat types					
	Island Head	Island Tail	Back channel	Main channel	Tributary	Deep hole
February 16 – 22, 2002						
Temp. (°C)					4.8 (0.35)	5.4 (-)
D. O. (mg/L)					13.3 (0.25)	13.6 (-)
Flow (m/s)					0.1 (0.02)	
Spec. Cond. (uS/cm)					390.1 (87.1)	373.0 (-)
March 9 - 25, 2002						
Temp. (°C)	7.7 (0.54)	7.1 (0.60)	6.9 (1.22)	7.3 (0.07)	6.8 (0.74)	7.3 (0.03)
D. O. (mg/L)	8.3 (0.49)	8.3 (0.53)	8.4 (0.58)	8.5 (0.46)	8.1 (0.49)	8.5 (0.52)
Flow (m/s)	0.5 (0.30)	0.3 (0.20)	0.4 (0.29)	0.4 (0.17)	0.1 (0.13)	0.4 (0.06)
Spec. Cond. (uS/cm)	353.3 (46.7)	354.6 (45.0)	355.6 (40.5)	338.7 (47.1)	316.2 (48.1)	337.9 (53.6)
April 4 - 7, 2002						
Temp. (°C)	9.0 (0.28)	9.0 (0.30)	9.0 (0.37)	8.9 (0.20)	9.4 (0.73)	8.9 (0.09)
D. O. (mg/L)	10.7 (0.67)	10.5 (0.26)	10.5 (0.26)	10.8 (0.85)	9.5 (1.64)	11.0 (1.12)
Flow (m/s)	0.6 (0.24)	0.4 (0.22)	0.7 (0.23)	0.7 (0.24)	0.2 (0.22)	1.0 (0.15)
Spec. Cond. (uS/cm)	265.9 (47.4)	267.0 (46.5)	267.4 (50.7)	261.9 (38.2)	282.2 (103.7)	250.9 (7.00)
February 16 – April 7, 2002						
Temp. (°C)	8.4 (0.80)	8.1 (1.07)	6.9 (1.39)	8.3 (0.84)	7.5 (2.25)	7.7 (1.31)
D. O. (mg/L)	9.6 (1.38)	9.5 (1.19)	9.4 (1.13)	9.9 (1.37)	10.0 (2.24)	10.3 (2.06)
Flow (m/s)	0.6 (0.27)	0.4 (0.21)	0.5 (0.30)	0.6 (0.28)	0.1 (0.17)	0.7 (0.35)
Spec. Cond. (uS/cm)	306.2 (64.0)	307.4 (63.2)	311.5 (63.8)	292.6 (56.1)	319.3 (92.0)	305.6 (61.2)

Table 1. continued.

Date	Habitat types					
	Island Head	Island Tail	Back channel	Main channel	Tributary	Deep hole
December 12 - 17, 2002						
Temp. (°C)	4.0 (0.55)	4.2 (0.56)	4.1 (0.52)	4.0 (0.47)	4.1 (0.74)	4.2 (0.42)
D. O. (mg/L)	7.3 (0.14)	8.5 (1.09)	7.9 (0.67)	7.2 (0.11)	7.1 (0.58)	8.4 (0.00)
Flow (m/s)	0.6 (0.29)	0.2 (0.10)	0.7 (0.21)	0.5 (0.26)	0.1 (0.13)	0.5 (0.15)
Spec. Cond. (uS/cm)	424.5 (80.6)	434.2 (76.3)	423.5 (91.7)	460.3 (60.5)	336.5 (95.3)	405.3 (61.0)
January 10 -19, 2003						
Temp. (°C)	2.3 (1.10)	2.7 (1.07)	2.5 (1.29)	2.5 (0.97)	2.1 (1.05)	3.0 (0.73)
D. O. (mg/L)	13.4 (0.17)	13.3 (0.60)	13.4 (0.23)	13.4 (0.67)	13.7 (0.33)	13.5 (0.49)
Flow (m/s)	0.4 (0.20)	0.1 (0.08)	0.4 (0.25)	0.4 (0.28)	0.1 (0.08)	0.6 (0.23)
Spec. Cond. (uS/cm)	443.0 (41.0)	434.2 (41.5)	446.8 (51.0)	428.4 (32.6)	417.9 (54.0)	404.6 (13.2)
March 1 -17, 2003						
Temp. (°C)	4.1 (1.47)	4.1 (1.44)	4.1 (1.39)	3.8 (1.31)	4.1 (1.96)	2.7 (1.03)
D. O. (mg/L)	13.2 (0.35)	13.0 (0.35)	13.0 (0.37)	12.4 (1.04)	11.8 (0.56)	12.9 (0.29)
Flow (m/s)	0.8 (0.24)	0.4 (0.15)	0.7 (0.14)	0.6 (0.43)	0.1 (0.13)	0.6 (0.21)
Spec. Cond. (uS/cm)	448.6 (69.7)	445.1 (69.4)	439.9 (73.0)	435.4 (66.6)	353.9 (97.7)	383.4 (56.4)
December 12, 2002 - March 17, 2003						
Temp. (°C)	3.1 (1.34)	3.4 (1.23)	3.3 (1.34)	3.3 (1.14)	3.1 (1.59)	3.6 (0.98)
D. O. (mg/L)	10.4 (2.19)	10.9 (2.03)	10.7 (2.00)	10.3 (2.24)	10.4 (2.69)	11.7 (2.19)
Flow (m/s)	0.5 (0.30)	0.2 (0.16)	0.5 (0.25)	0.5 (0.33)	0.1 (0.11)	0.6 (0.19)
Spec. Cond. (uS/cm)	433.8 (62.8)	434.2 (60.5)	435.7 (70.0)	444.4 (53.8)	377.2 (86.6)	415.0 (46.8)

Chapter 3. Juvenile Use of a Large River Embayment during Winter

Abstract

The severity of winter conditions regulates juvenile fish mortality rates. Identifying habitats used by juveniles is essential for understanding where fishes survive during winter. Shallow, low-gradient, off-channel embayments, like Little Sandy Creek adjacent to the Ohio River, are ideal refuges for overwintering juvenile species. Eighty-five percent of all fishes collected in Little Sandy Creek embayment during this study were juveniles. Many of the fishes collected were juvenile sunfish (Centrarchidae). Bluegill, *Lepomis macrochirus*, and white crappie, *Pomoxis annularis*, were the dominant sunfishes collected. Protecting and modifying embayment habitats may reduce juvenile mortality during winter and improve recreational angling opportunities for sunfish in large river systems.

Introduction

Winter, a critical period for juvenile riverine fishes in temperate climates, reduces probabilities of survival (Bodensteiner and Lewis 1992; Lyons 1997) and recruitment (Oliver et al. 1979; Toneys and Coble 1979; Miranda and Hubbard 1994). Fishes enter a torpor-like state during low winter temperatures (Crawshaw 1984) where metabolic rates and consequently, respiration and activity rates are low (Bodensteiner and Lewis 1992; Carlson 1992; Cunjak 1996). Fishes increase fat-reserves before winter; hence, reducing mortality associated with energy depletion (Post and Evans 1989; Cargnelli and Gross 1996). During torpor, however, juvenile fishes are susceptible to predation (Garvey et al. 1998) and adverse physiochemical conditions, such as low dissolved oxygen concentrations and strong current velocities (Cunjak 1996). Consequently, optimal

winter habitats should provide protection from predators as well as amiable abiotic conditions that minimize energy depletion (Crawshaw 1984).

Riverine fishes overwinter in areas of low flow and relatively warm temperatures (Logsdon 1993; Bodensteiner and Lewis 1994; Johnson et al. 1998), such as off-channel coves, backwaters, marinas, embayments and industrial warm-water outflows (Sheehan et al. 1990; Gent et al. 1995; Knights et al. 1995; Raibley et al. 1997; Sheehan and Rasmussen 1999). Although riverine fishes select thermal refuges and areas of relatively low flow during winter, high winter mortality rates of juvenile fishes have been documented (Bodensteiner and Lewis 1992; Lyons 1997). Rates of juvenile survival influence numbers of individuals recruited into future fisheries (Toneys and Coble 1979; Miranda and Hubbard 1994). Given the link between winter temperature and fish mortality, and the importance of juvenile survival to fishery recruitment, fishery managers need to locate and protect winter refuge habitats of juvenile fishes.

In the Ohio River, channelization and impoundment from lock and dams have homogenized habitats, and reduced low-velocity mainstem habitats. However, embayments, shallow off-channel areas, offer low-velocity habitat for fishes during winter. Embayments contain riverine fishes during winter (Sheehan et al. 1990; Gent et al. 1995; Knights et al. 1995; Raibley et al. 1997), but their importance in the Belleville Pool of the Ohio River was undocumented before this study.

Objectives

Our primary objective was to examine species composition and size classes (juveniles vs. adults) of fishes in Little Sandy Creek embayment, Belleville Pool, Ohio River, West Virginia, during winter 2002-2003. A secondary objective was to quantify

age-length relationships of white crappie, *Pomoxis annularis*, a popular sport fish for recreational anglers. This study was part of a larger evaluation of winter habitats used by fishes in main channels, island back channels, island heads and tails, and tributary mouths within Belleville Pool (see Chapter 2).

Study site

Little Sandy Creek drains 26 sq. km and includes a 12.4 ha embayment (39° 13' 57" N, 81° 41'10" W) near its confluence with the Ohio River. The embayment reaches a maximum 2 m channel depth, but is mostly shallow (< 0.5 m) during normal flows. The riparian zone is a mixture of agricultural fields, mixed deciduous forest, and housing developments.

Methods

Data collection

During the winter of 2002-2003, we electrofished (Smith-Root pulsed DC electrofishing boat) Little Sandy Creek embayment on 15 December 2002, and 1 and 17 March 2003. On each sample date, we electrofished two near-shore transects and one mid-channel transect. Transects were sampled for 10 minutes (peddle time). Ice cover prevented sampling during January and February. Fishes were captured, identified to species, measured (nearest mm total length, TL), and weighed. Weights for large fishes (over 1kg) were taken to the nearest 25g with a Pesola spring scale (5 kg maximum). Smaller fishes (less than 1 kg) were weighed to the nearest 1g with a Homs spring dial scale (1kg maximum). After measuring the weights and lengths of 100 individuals of a species collected during a single sample date, the remaining individuals were counted, (except for emerald shiner, *Notropis atherinoides*, due to its extremely small size). When

collected, five white crappie individuals from each 50 mm size class were kept during each sample date for age analysis.

To describe the abiotic conditions of Little Sandy Creek embayment, we measured specific conductivity, dissolved oxygen (D. O.), pH, and temperature with an YSI 6820 during each sample date. Additionally, we estimated turbidity (secchi disk, and NTUs with YSI 6820), and flow velocity (Marsh-McBirney Flowmate 2000).

Length-at-maturity and age analysis

To evaluate the importance of Little Sandy Creek embayment to juvenile fishes, we defined juveniles (except white crappie) based on published length-at-maturity data from Trautman (1981), Mittelbach (1984), Etnier and Starnes (1993), Jenkins and Burkhead (1993), and Johnson and Jennings (1998). We defined white crappie individuals as juveniles or adults based on our age estimates.

We examined age structure of white crappie with otoliths. Otoliths were removed from a subset of the white crappie, sectioned with an Isomet 1000 precision saw with a 12.7 cm x 0.4 mm blade, and viewed with a dissecting scope. Two observers estimated age independently, and a third observer resolved discrepancies. In order to simplify the aging process because these fish were collected in winter, we assumed January 1 as the birth date (DeVries and Frie 1996) and assigned ages as if all individuals were collected on or after January 1.

Statistical analysis

We used length-frequency distributions for the five most abundant species and compiled the information from the sources listed above for the least abundant species to establish juvenile length ranges for all species collected in Little Sandy Creek

embayment. We calculated the proportion of juveniles of each species by sampling dates. To further classify the age-length distribution of white crappie, the length range, mean length, and variance were calculated for each white crappie age class.

Results

Abiotic conditions

Water temperatures rose from 2.95 to 11.24 °C between 1 and 17 March 2003. During the 15 December 2002 sample, the water temperature was 4.08 °C. Dissolved oxygen ranged from 11.16 to 11.75 mg/L. Specific conductivity (uS/cm) values were 257.3, 257, and 350, and pH values were 6.9, 7.3, and 7.7 during the first, second, and third sample dates, respectively. A null flow velocity measurement (0 m/s) was recorded during all three sample dates. Turbidity (NTU) was lowest during the March 1 sample (55) and highest during the March 17 sample (84). Secchi disk readings corresponded with the turbidity measurements, the highest value recorded during March 1 (39 cm) and the lowest during March 17 (25 cm).

Fish species and abundance

Juveniles represented the majority of the individuals collected in the Little Sandy Creek embayment during winter. Eighty-five percent of all fishes collected were juveniles (Table 2). The five most abundant species, gizzard shad, *Dorosoma cepedianum*, bluegill, *Lepomis macrochirus*, emerald shiner, white crappie, and orangespotted sunfish, *Lepomis humilus*, represented 96% of the total catch (Table 2). Of these five most abundant species, juveniles represented 83% of the total individuals. The length frequency distributions for these five species also show that shorter individuals (juveniles) were more numerous than longer individuals (Figure 6). Nearly all (97% and

94%, respectively) of the gizzard shad and orangespotted sunfish individuals were juveniles (Table 2). Of the 305 centrarchid individuals collected, 81% were juvenile. Interestingly, the proportion of the total individuals represented by juveniles decreased during the March 1 and 17, 2003 sample dates (Table 2).

Seventeen species were collected during the three sampling periods (Table 2). Fish numbers differed among sample periods (717 individuals on 15 December, 52 on 1 March, and 121 on 17 March) (Table 2). The most abundant fish, gizzard shad, was only collected in large abundance during a single sample date, December 15. One each of bowfin, *Amia calva*, mosquitofish, *Gambusia affinis*, and smallmouth buffalo, *Ictiobus bubalus*, were collected during all sample periods, none of which were juveniles. Only one fish, white crappie, was consistently collected in relatively equal numbers and abundance (Table 2).

Five different size classes of white crappie were collected representing age classes one through five (Table 3 and Figure 6d). Eighteen age-one (juvenile) white crappie represented 29% of the aged individuals. Age-two white crappies were most abundant, representing 40% of the aged individuals. Age-three, four, and five white crappies consisted of 14.5%, 8%, and 8%, respectively, of the aged individuals.

Discussion

The Little Sandy Creek embayment, a shallow off-channel, low velocity habitat, provides an important winter refuge for juvenile fishes. The upper Ohio River, with steep topography and a restricted channel, lacks the slow-moving isolated sloughs found in other large river systems in temperate North America. Embayments in the upper Ohio River, however, are similar in abiotic characteristics to other large river backwater

habitats that are important overwintering habitats for fishes of all ages (Sheehan et al. 1990; Gent et al. 1995; Knights et al. 1995; Raibley et al. 1997; Sheehan and Rasmussen 1999). Previous to this study, the value of these shallow, low-velocity, off-channel habitats, specifically for overwintering juvenile fishes, was undocumented.

The shallow, low-gradient physical characteristics of embayments make them ideal refuges for overwintering fishes. However, reductions in flow velocities in backwaters and embayments coupled with ice-cover can lead to low D. O. concentrations (Bodensteiner and Lewis 1992; Knights et al. 1995; Johnson et al. 1998). This reduction in D. O. content may either cause mortality in fishes or force them to seek alternative overwintering refuges in other habitat types. We do not know whether or not D. O. levels decreased below sufficient levels for fishes during the ice cover event in January and February 2003, but the measured D. O. concentrations were above critical minimal values before and after ice cover in Little Sandy Creek. Regardless of flow conditions, when temperatures fall below 4 °C, fishes may prefer warmer habitats, if available. In laboratory settings, Sheehan et al. (1990) reported temperature preferences of > 4 °C for many species in large rivers, such as green sunfish, *Lepomis cyanellus*, bluegill, and freshwater drum, *Aplodinotus grunniens*. Our data collected on species residing in the mainstem portions of the Ohio River show that some fishes will select higher-velocity warmer habitats over lower velocity colder habitats during winter (see Chapter 2). Increased mortality of fishes may occur because they cannot survive the low temperatures or dissolved oxygen concentrations in an embayment, forcing them to inhabit suboptimal habitats in the mainstem portions of large rivers. Fishery managers can modify

embayments to better suit the abiotic requirements of overwintering fishes to avoid increased mortalities due to these factors.

Given that centrarchids are popular game fishes, recreational fishery managers may want to consider the importance of embayments as overwintering sites for juvenile centrarchids of all ages, (but especially juveniles since they are the most susceptible to winter mortality), and protect these habitats. In our study, eight of the 17 species were comprised primarily juveniles of bluegill, green sunfish, orangespotted sunfish, pumpkinseed, *Lepomis gibbosus*, warmouth, *Lepomis gulosus*, white crappie, black crappie, and largemouth bass, *Micropterus salmoides*. Juvenile and adult white crappie used Little Sandy Creek embayment during winter, stressing the importance of this habitat for this species. Adult centrarchids use embayments during winter because of the low flow velocities (Oliver et al. 1979; Knights et al. 1995; Johnson et al. 1998; Jackson and Noble 2000). Juvenile centrarchids may use embayment habitats during winter to avoid predation. Santucci and Wahl (2003) reported 75 % to 85 % mortality rates during the first winter of young-of-the-year bluegills due to predation by largemouth bass. We captured few large predatory fishes during our samples, and juveniles were primarily associated with near-shore structure (overhanging vegetation, woody debris, and undercut banks). The use of structure by juveniles to avoid predation is well documented (Mittelbach 1988; Gotceitas 1990; Miranda and Hubbard 1994). The addition of woody debris into embayments would increase the amount of cover offering escape from predation, possibly increasing survival of juveniles.

A reduction of the proportion of juveniles in Little Sandy Creek embayment during the course of this study may have been due to mortality loss from the severely

cold temperatures during the winter of 2002-2003. High winter mortality rates of juvenile freshwater drum in the Mississippi River have been documented when water temperatures approached 0 °C (Bodensteiner and Lewis 1994). We believe water temperatures within Little Sandy Creek embayment approached 0 °C during ice-cover in January and February. Low levels of dissolved oxygen during ice-cover of backwater areas have increased mortality of fishes (Bodensteiner and Lewis 1992; Knights et al. 1995; Johnson et al. 1998). These critically low temperatures (coupled with possible reductions in D. O. concentrations) may have led to increased mortality, which explains the reduction in the numbers of total individuals present in early March, after the embayment thawed.

Increasing flow rates to minimal levels (> 0) in embayments could limit mortality losses due to insufficient dissolved oxygen levels. Knights et al. (1995) showed that overwintering bluegill and black crappie, *Pomoxis nigromaculatus*, required flow velocities > 0 cm/s, but ≤ 1 cm/s to ensure dissolved oxygen concentrations > 2 mg/ L in backwater lakes of the Mississippi River. Increasing flows > 1 cm/s rendered these habitats unsuitable to these centrarchid species (Knights et al. 1995; Johnson et al. 1998). In the Ohio River, reduction in the elevation of the impounded pool of water during freezing temperatures would allow minimal flows in and out of embayments, reducing the probability of hypoxia. Care would need to be taken to avoid releasing water so quickly that flow velocities in the embayments carry fishes (especially juveniles) out of these areas into the main channel of the river. Extended research into the specific flow velocity requirements of fishes during winter would provide more insight into how embayments can be manipulated in order to improve juvenile survival during winter.

In summary, the severity of winter conditions regulates juvenile fish mortality rates (Bodensteiner and Lewis 1994; Post et al. 1998; Wright et al. 1999; Fullerton et al. 2000; Jackson and Noble 2000). Shallow low-velocity embayments offer a refuge for juvenile fishes so as to improve their probability of survival during winter. Protection, creation, and modification of embayment habitats may reduce juvenile mortality and spur increased sunfish production in large river systems by providing critical overwintering habitat. Whether modified or not, those embayment habitats that offer low current velocities (≤1 cm/s), warmer temperatures (≥4 °C), and sufficient dissolved oxygen levels (≥2 mg/L), can be beneficial to overwintering juvenile fishes.

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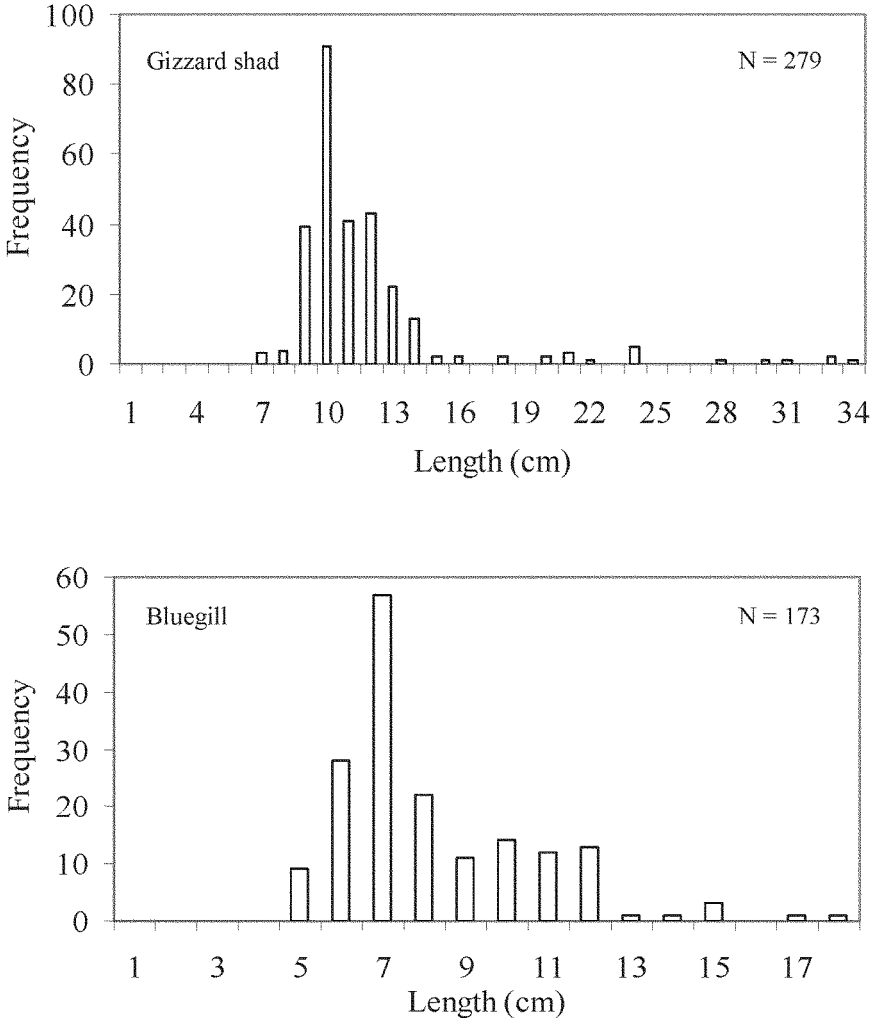
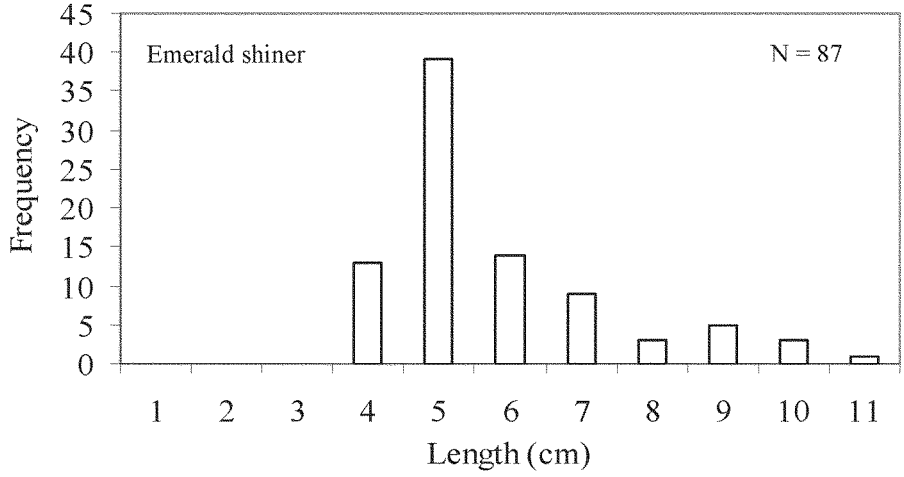
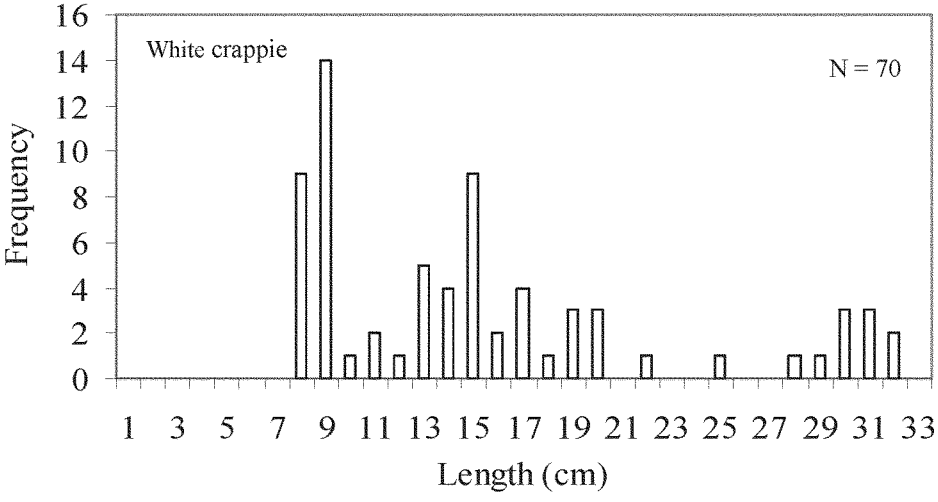
Figures and Tables

Figure 6. Length-frequencies of gizzard shad, bluegill, emerald shiner, white crappie, and orangespotted sunfish collected by pulsed DC electrofishing in the Little Sandy Creek embayment, West Virginia, during December 15, 2002 through March 17, 2003.




Emerald shiner
N = 87
Frequency
45
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11
Length (cm)


White crappie
N = 70
Frequency
16
14
12
10
8
6
4
2
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33
Length (cm)

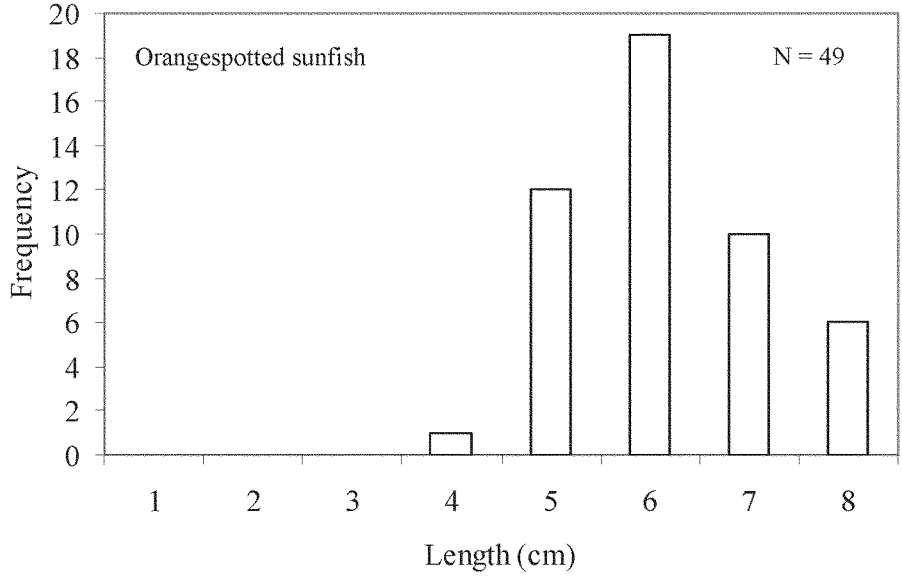

Orangespotted sunfish
N = 49
Frequency
20
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
Length (cm)

Table 2. Total number of individuals and juvenile proportion of the total for each fish species collected by pulsed DC electrofishing in the Little Sandy Creek embayment, West Virginia, during December 15, 2002 through March 17, 2003. Values in parentheses are the proportion of the total individuals represented by juveniles for that sampling date.

Taxon	Number collected 15-Dec-02	1-Mar-03	17-Mar-03	Total	Juvenile proportion
Black crappie *Pomoxis nigromaculatus*	1	0	1	2	1
Bluegill *Lepomis macrochirus*	113	10	41	164	0.85
Bowfin *Amia calva*	0	0	1	1	0
Common carp *Cyprinus carpio*	0	0	3	3	0
Emerald shiner *Notropis atherinoides*	120	1	16	137	0.68
Freshwater Drum *Aplodinotus grunniens*	4	0	2	6	0.5
Gizzard shad *Dorosoma cepedianum*	404	5	21	430	0.97
Green sunfish *Lepomis cyanellus*	3	1	3	7	0.29
Largemouth bass *Micropterus salmoides*	0	2	1	3	0.33
Mosquitofish *Gambusia affinis*	1	0	0	1	0
Orangespotted sunfish *Lepomis humilis*	35	6	8	49	0.94
Pumpkinseed *Lepomis gibbosus*	0	3	2	5	0.2
River carpsucker *Carpiodes carpio*	0	0	4	4	1
Smallmouth buffalo *Ictiobus bubalus*	0	0	1	1	0
Spotted sucker *Minytrema melanops*	1	1	0	2	0
Warmouth *Lepomis gulosus*	2	2	1	5	0.2
White crappie *Pomoxis annularis*	33	21	16	70	0.79
Total	717 (0.92)	52 (0.65)	121 (0.44)	890	0.83

Table 3. The length range, mean length, and variance at age for white crappies collected by pulsed DC electrofishing in the Little Sandy Creek embayment, West Virginia, during December 15, 2002 through March 17, 2003.

Age	Length range (cm)	Mean length (cm)	Variance (cm)	Number collected
1	6.1 – 10.2	7.6	1.1	18
2	12 – 17.2	13.8	2.4	25
3	16.8 – 23.2	19.4	5.3	9
4	26.1 – 28.6	27.4	0.8	5
5	29.4 – 30.9	29.4	0.3	5

Chapter 4. Growth Assessment of three Sport Fishes of the Ohio River

Abstract

Channel catfish, *Ictalurus punctatus*, freshwater drum, *Aplodinotus grunniens*, and white bass, *Morone chrysops*, are popular sport fishes in the Ohio River. Standard age and growth statistics were computed to assess the population growth and condition of these fishes. Channel catfish reached larger mean-lengths at all ages compared to specimens collected over 30 years ago in the Ohio River. Numerous older and larger freshwater drum individuals were collected, suggesting plentiful trophy-sized individuals exist in the Ohio River. None of the white bass collected were harvestable size, suggesting larger individuals may use different habitats than smaller individuals or that environmental conditions are unsuitable for appreciable growth of this species in the Ohio River. Although the population status appears satisfactory for channel catfish and freshwater drum, more information is needed to better assess the condition of white bass in the Ohio River.

Introduction

Channel catfish, *Ictalurus punctatus*, freshwater drum, *Aplodinotus grunniens*, and white bass, *Morone chrysops*, are popular gamefishes of the Ohio River, West Virginia. Currently, harvest regulations for the Ohio River, West Virginia, do not restrict lengths or numbers of channel catfish and freshwater drum, but impose a daily creel limit of four white bass > 38 cm. Little published information exists on the population dynamics of these three fishes in West Virginia waters of the Ohio River. An

understanding of age, length, and weight relationships of these important fishes is needed to manage and maintain viable recreational fisheries (Anderson and Neumann 1996).

Channel catfish live to a maximum age of 24 years and can attain weights of 34 kg (Etnier and Starnes 1993). In 1973, Schoumacher reported a maximum mean length of 43 cm at age eight for Ohio River specimens. Quist and Guy (1998) also reported a maximum age of eight for channel catfish specimens from the Kansas River, but the mean length at age eight was a greater 59 cm. Maximum ages and mean lengths reported for freshwater drum differ, however, a maximum age of 10 to 11 years and a mean length of 69 cm generalizes Goeman et al. (1984), Etnier and Starnes (1993), and Braaten and Guy (2002). The maximum age of white bass from Tennessee is 8 (Etnier and Starnes 1993), while Colvin (2002) recorded age-7 white bass specimens from the Missouri River.

Objectives

The objective of this study was to document growth relationships of channel catfish, freshwater drum, and white bass from Belleville Pool, Ohio River, West Virginia. Age-frequency distributions, the von Bertalanffy growth equation (Ricker 1975) and the allometric growth equation are used in this analysis in order to assess the population condition, structure, and growth of these three commonly occurring sport fishes in the Ohio River.

Study site

The Belleville Pool of the Ohio River, created by Belleville Lock and Dam (rkm 328.1), extends upstream to Willow Island Lock and Dam (rkm 260.2). The 67.9 km pool averages 404.5 m wide, 7.3 m deep, and comprises 2850 ha of surface area

(ORSANCO 1994). The deepest section of the pool (15 m) lies directly upstream of Belleville Lock and Dam. A navigation channel (3.7 m deep) is maintained for commercial barge traffic by the United States Army Corps of Engineers (USACE) (ORSANCO 1994). The riparian zone is a mixture of hardwood forests, urban and industrial frameworks, and agricultural settings. Most large floodplains near Belleville Pool are heavily urbanized, including cities of Parkersburg, WV (confluence of the Little Kanawha and Ohio rivers) and Marietta, OH (junction of Muskingum and Ohio rivers).

Methods

Data collection

We sampled the Belleville Pool during two periods (February 2002 – April 2002, and December 2002 to March 2002) with a variable-depth AC electrofishing boat for water depths of 2-15 meters (Grunwald 1983, Newcomb 1989). Fishes were identified to species, measured (nearest mm total length, TL), and weighed. Large fishes (over 1 kg) were weighed to the nearest 25 g with a Pesola spring scale (5 kg maximum). Smaller fishes (less than 1 kg) were weighed to the nearest 1g with a Homs spring dial scale (1 kg maximum). When collected, five individuals from each 50 mm size class of channel catfish, freshwater drum, and white bass were frozen for age analysis.

Age analysis

Sagittal otoliths were extracted from freshwater drum and white bass and sectioned with an Isomet 1000 precision saw with a 12.7 cm x 0.4 mm blade (DeVries and Frie 1996). Transverse otolith sections (approximately 1 mm thickness) were stained with iodine. When illuminated, most small otoliths (age classes 0-2, especially in freshwater drum) were aged without sectioning. Pectoral spines of channel catfish were

removed and softened in 4% nitric acid solution (HNO_3) (K. Hartman pers. comm.). Each spine was sectioned at the distal end of the basal groove (Sneed 1951) with a single-edge razor blade. Annuli of otolith and pectoral spine sections were counted under magnification (2-4 X). Two observers estimated age independently, and a third observer resolved discrepancies. In order to simplify the aging process because these fish were collected in winter, we assumed January 1 as the birth date (DeVries and Frie 1996) and assigned ages as if all individuals were collected on or after January 1.

Mean length for each age class and the variance of these values were calculated for all species. The frequency of each age class for all species was also calculated. We used the von Bertalanffy (Ricker 1975) equation $L_t = L_\infty * (1 - e^{(-K * t_0)})$ to describe the relationship of age and length of these three species. This equation calculated L_t (length at a specific age) values for channel catfish, freshwater drum, and white bass by estimating the asymptotic length (L_∞ (cm)), growth coefficient (K), and t_0 (theoretical age in years when length = 0). Standard errors of these three parameters were also calculated. We also used the allometric growth equation $W = aL^b$, where W = weight (g), a = y-intercept, and b = slope, and L = length (mm), to describe the length-weight relationship of the three species. Standard errors of the slope and y-intercept were also calculated.

Results

Younger age classes represented the greatest proportion of individuals of white bass and freshwater drum (Figure 7). The greatest number of individuals was age-4 for channel catfish, age-1 for freshwater drum, and age-2 for white bass (Figure 7). Freshwater drum were represented by the oldest age class (22), while the oldest age classes of channel catfish and white bass were 9 and 4, respectively (Table 4). The

longest freshwater drum individual was 77 cm, 62 cm for channel catfish, and approximately 30 cm for white bass (Table 4). Surprisingly, no white bass individuals collected were longer than the harvest minimum size limit of > 38 cm. High variances of mean-length-at-age values occurred due to low sample sizes for older age classes of freshwater drum and most age classes of channel catfish (Table 4).

The growth parameters calculated by the von Bertalanffy and allometric growth equations varied between the three species. The von Bertalanffy growth parameter estimates are as follows: for channel catfish, the L_∞ = 113 cm (SE = 1.34), K = 0.077 (SE = 0.056), and t_0 = 1.71 (SE = 0.46) (Figure 8a); for freshwater drum, the L_∞ = 118 cm (SE = 6.82), K = 0.051 (SE = 0.013), and t_0 = 1.47 (SE = 0.38) (Figure 8b); for white bass, the L_∞ = 48 cm (SE = 3.36), K = 0.248 (SE = 0.32), and t_0 = 1.16 (SE = 0.21) (Figure 8c). The allometric growth parameter estimates are as follows: for channel catfish, the slope = 3.35 (SE = 0.268), and y-intercept = 1.0×10^{-6} (SE = 2.35×10^{-7}) (Figure 9a); for freshwater drum, the slope = 3.39 (SE = 0.179), and y-intercept = 1.0×10^{-6} (SE = 1.12×10^{-7}) (Figure 9b); for white bass, the slope = 3.13 (SE = 0.492), and y-intercept = 1.7×10^{-6} (SE = 4.61×10^{-7}) (Figure 9c).

Discussion

White bass growth appears to be deficient for angling harvest in the upper Ohio River. It is possible that we failed to locate larger white bass individuals in the habitats we sampled, but none of the individuals collected were greater than the minimum size limit set for harvest, > 38 cm, by the West Virginia Department of Natural Resources (Table 4). Even though the von Bertalanffy maximum length (L_∞) value was 48 cm and the growth coefficient (K) was highest of all species, collected white bass individuals did

not approach harvestable size. Our L_{∞} value for white bass agrees with Colvin's Missouri River specimens (2002), while our K value is considerably lower, denoting that Ohio River white bass may attain relatively equal maximum sizes but at a slower rate. White bass specimens from the Roach Lake, Ohio had mean lengths (cm) of 14.0, 26.9, and 36.6 for ages 1, 2, and 3, respectively (Carlander 1997), substantially larger sizes than our Ohio River specimens (Table 4). Our mean-length-at-age estimates for the four white bass age classes measured were considerably less than those from Tennessee (Etnier and Starnes 1993), further suggesting that white bass growth in the Ohio River is limited.

Channel catfish growth is extremely variable across spatial and temporal boundaries (Etnier and Starnes 1993). Our low von Bertalanffy K value suggests channel catfish are not growing quickly in the upper Ohio River. However, our mean-length-at-age estimates for channel catfish were higher for all age classes than Schoumacher's (1973) Ohio River specimens (also taken from the Belleville Pool). Mississippi River specimens were reported as having mean lengths (cm) of 15.0, 21.1, and 25.4 for ages 2, 3, and 4, respectively (Carlander 1969), also significantly less than our Ohio River specimens. However, our maximum mean length agrees with the mean-length-at-age 8 (Table 4) from Tennessee (Etnier and Starnes 1993) and Kansas River specimens (Quist and Guy 1998). This suggests that channel catfish in the upper Ohio River may be growing at a higher rate and attaining larger sizes faster than in the past.

Freshwater drum reach considerable sizes in the Belleville Pool, Ohio River. The maximum age estimate for our freshwater drum specimens (Table 4) is greater than most published information. The oldest freshwater drum individual collected in the Belleville Pool was estimated to be 22 years of age, measured 77 cm in length, and weighed 7.4 kg.

In Lake Erie, Cunningham (1989) recorded a 33-yr old freshwater drum and numerous individuals older than 10 years. A relatively large number of freshwater drum individuals collected were of older age classes (> 10) (Figure 7b and Table 4), suggesting that conditions in the upper Ohio River are favorable for long life expectancy of freshwater drum.

In summary, the age and growth information presented here is useful in assessing the population growth and condition of these three popular sport fishes in the Ohio River. None of the white bass collected were harvestable size, possibly indicating larger white bass either use different habitats than smaller individuals or sub optimal environmental conditions exist in the Belleville Pool for this species. Channel catfish appear to be growing at faster rates than in the past, suggesting environmental conditions have improved for this species over time. The impressive sizes that freshwater drum reach in the Belleville Pool should delight any angler seeking trophy-sized individuals of this species. Hopefully, this information proves useful for fishery managers seeking to improve conditions or assess past management actions for these three sport fisheries in the Ohio River.

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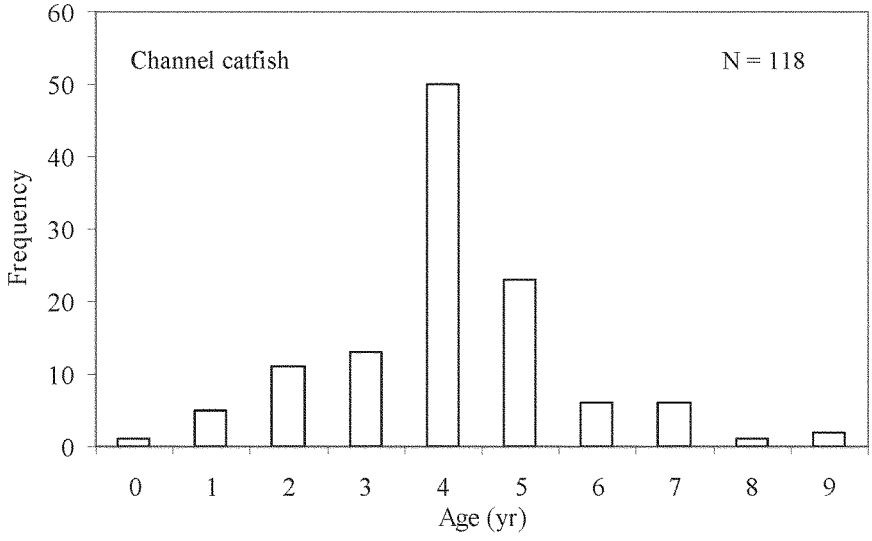
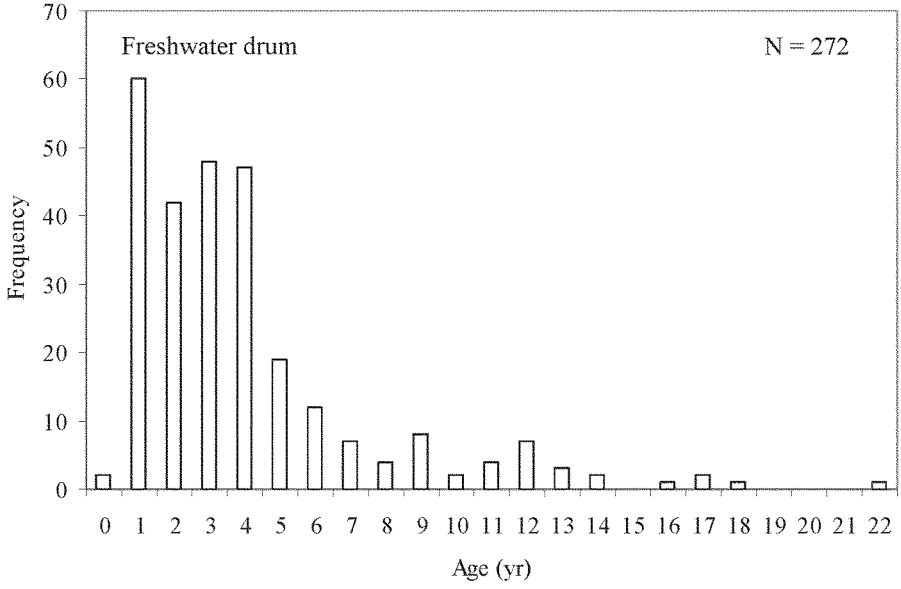
Figures and Tables

Figure 7. The age frequencies of channel catfish, freshwater drum, and white bass collected in the Belleville Pool, Ohio River during February 17 through April 7, 2002 and December 12, 2002 through March 17, 2003.




Freshwater drum
N = 272
Frequency
Age (yr)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
0 10 20 30 40 50 60 70

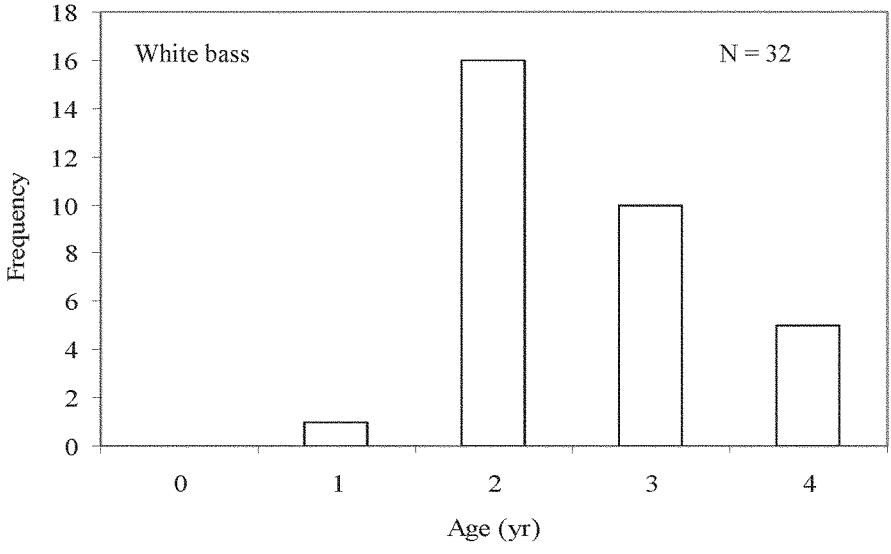
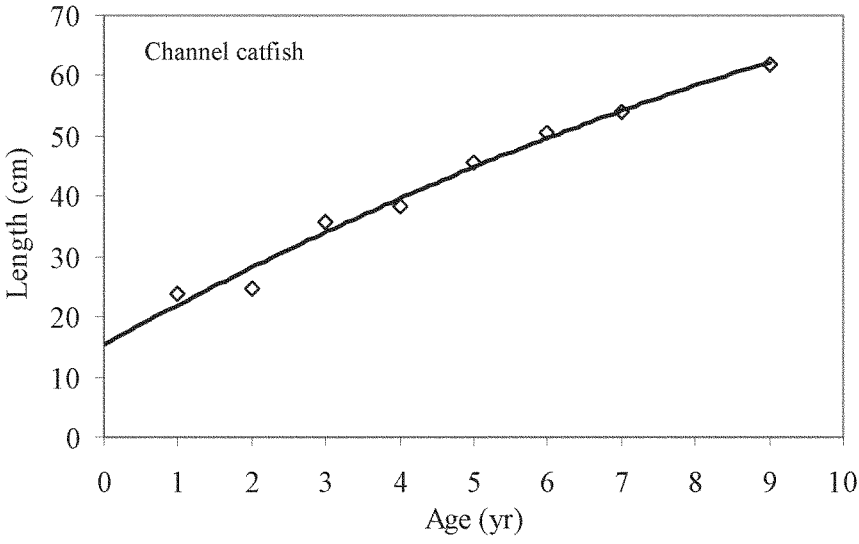
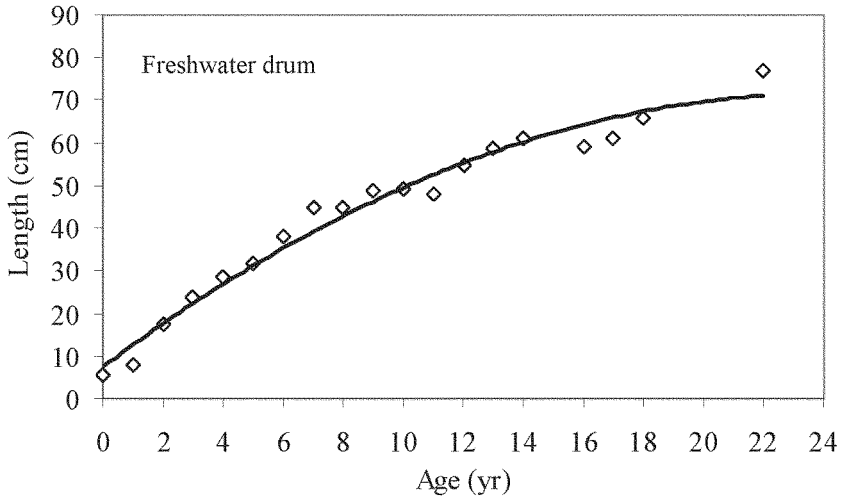

White bass
N = 32
Frequency
Age (yr)
0 1 2 3 4
0 2 4 6 8 10 12 14 16 18

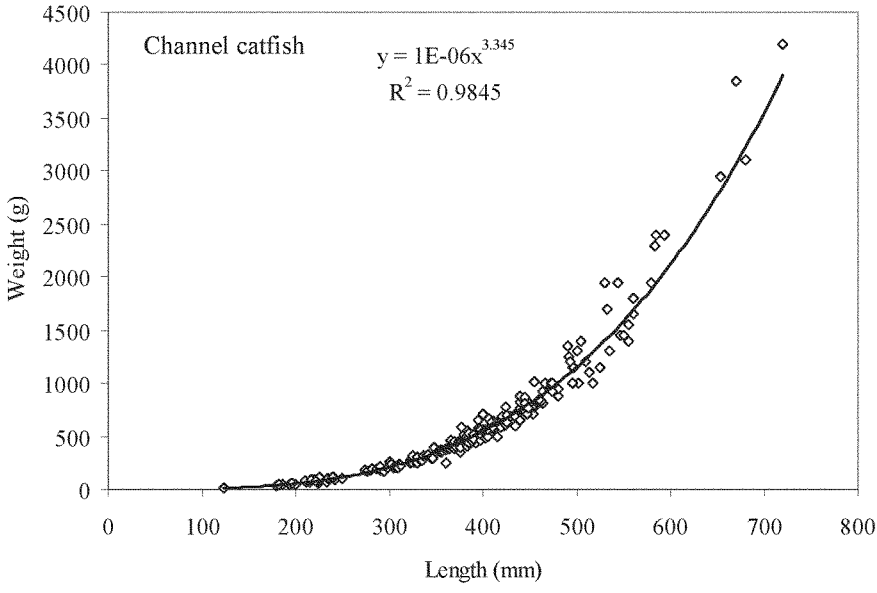
Figure 8. The von Bertalanffy growth curves of channel catfish, freshwater drum, and white bass collected in the Belleville Pool, Ohio River.

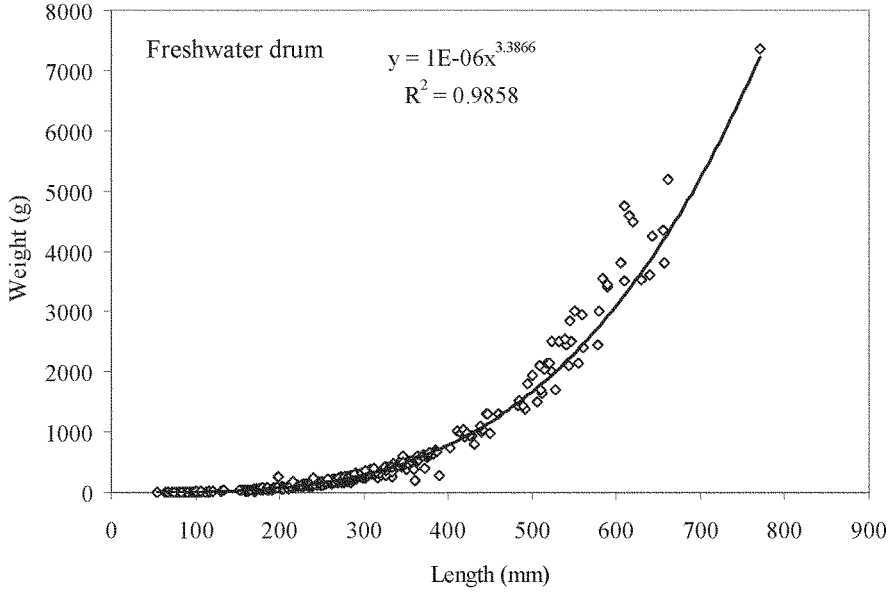



Freshwater drum
Length (cm)
Age (yr)
0
10
20
30
40
50
60
70
80
90
0
2
4
6
8
10
12
14
16
18
20
22
24

White bass
Length (cm)
Age (yr)
0
5
10
15
20
25
30
35
1
2
3
4
5

Figure 9. The allometric growth of channel catfish, freshwater drum, and white bass collected in the Belleville Pool, Ohio River.




Freshwater drum
y = 1E-06x^3.3866
R^2 = 0.9858
Weight (g)
Length (mm)
8000
7000
6000
5000
4000
3000
2000
1000
0
0
100
200
300
400
500
600
700
800
900

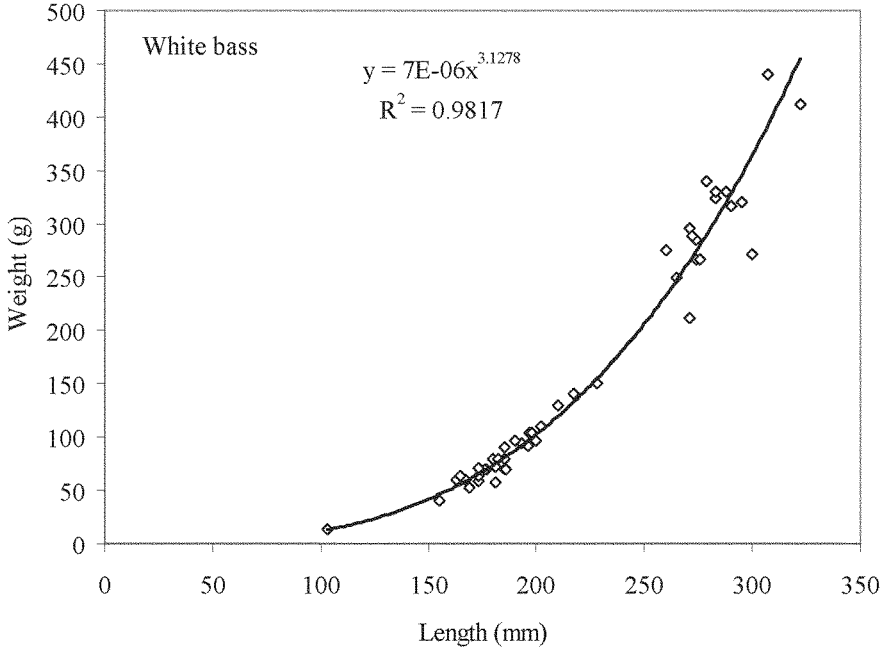

White bass
y = 7E-06x^3.1278
R^2 = 0.9817
Weight (g)
Length (mm)
0
50
100
150
200
250
300
350
400
450
500

Table 4. Mean length-at-age of channel catfish, freshwater drum, and white bass collected in the Belleville Pool, Ohio River during February 17 through April 7, 2002 and December 12, 2002 through March 17, 2003. Variances are in parentheses; no values indicate only one individual for that age group was collected.

	Mean length (cm)					
Age	Channel catfish		Freshwater drum		White bass	
0	23.8	(9.7)	5.5	(0.5)		
1	24.8	(39.7)	8.0	(1.6)	11.2	
2	35.6	(19.4)	17.3	(8.2)	18.8	(3.4)
3	38.4	(40.7)	23.8	(2.5)	27.8	(0.8)
4	45.6	(37.8)	28.6	(5.6)	30.4	(1.3)
5	50.5	(55.5)	31.6	(5.4)		
6	54.0	(53.2)	37.9	(8.1)		
7	56.8	(46.8)	45.0	(27.6)		
8	59.2		44.8	(63.6)		
9	62.0	(32.0)	48.7	(5.9)		
10			49.0	(32.0)		
11			48.0	(36.0)		
12			54.7	(21.2)		
13			58.7	(37.3)		
14			61.0	(8.0)		
16			59.0			
17			61.0	(18.0)		
18			66.0			
22			77.0			

SUMMARY

Winter is a critical period during which fishes suffer increased mortality. During winter conditions, fishes select refuge habitats where physiochemical factors are unlikely to exceed tolerance limits. In large temperate river systems, such as the Ohio River, extremely low water temperatures during winter coupled with high flows could be expected to increase mortality rates of fishes. Juvenile fishes are most susceptible to winter mortality due to their small size and lack of energy reserves. The greatest diversity and abundance of fishes were collected by electrofishing in the Belleville Pool, Ohio River, in low-velocity tributary confluences and an embayment at temperatures > 3 - 4 °C. When water temperatures were < 3 °C, more individuals of certain species were collected in faster-velocity main channel and back channel habitats. Other species collected at temperatures < 3 °C continued to associate with the lower flows in tributaries. The lack of water temperatures > 4 °C in tributaries may have left some fishes susceptible to current velocity, which carried them into channel habitats.

Species- and age-specific responses to winter conditions may obscure broad generalizations about when and how certain species use overwintering refuges. For example, in the Little Sandy Creek embayment, adjacent to the Belleville Pool, 85% of all fishes collected were juveniles. Centrarchids, popular sport fishes, while collected in low numbers in the mainstem portion of the river, were one of the dominant fishes collected in the embayment. Protecting and modifying embayment habitats may reduce juvenile mortality during winter and improve recreational angling opportunities for sunfish in large river systems

Populations of channel catfish, *Ictalurus punctatus*, and freshwater drum, *Aplodinotus grunniens*, the most abundant fishes collected in the Belleville Pool, exhibit satisfactory population growth and condition. Channel catfish reach larger mean-lengths at all ages compared to specimens collected over 30 years ago in the Belleville Pool. Numerous older and larger freshwater drum individuals were collected, suggesting plentiful trophy-sized individuals exist in the Ohio River. Conversely, none of the white bass, *Morone chrysops*, individuals collected were harvestable size. Fishery managers can use this information to assess the population growth and condition of these three species and make management decisions according to their goals for each species. Possibly, the population growth and the probability of survival of fishes of all ages may increase by protecting and enhancing tributary and embayment habitats in large rivers during winter.

APPENDIX A

Fish caught per hour (CPUE) within each habitat type in the Belleville Pool, Ohio River. No values indicate habitat not sampled.

February 2002 session

	Habitat types						
	Island		Back	Main		Deep	
Species	Head	Tail	channel	channel	Trib	hole	Total
Emerald Shiner			0		1.6	0	1.0
Freshwater Drum			0		6.5	0	4.2
Gizzard Shad			0		68.5	0	43.6
River Carpsucker			0		1.6	0	1.0
Total			0		78.3	0	49.8

March 2002 session

	Habitat types						
	Island		Back	Main		Deep	
Species	Head	Tail	channel	channel	Trib	hole	Total
Channel Catfish	4.4	0	3.2	1.1	65.4	0	11.1
Common Carp	0	0	0	0	3.9	0	0.6
Emerald Shiner	0	0	0	0	2.9	0	0.4
Freshwater Drum	0	0	0.8	2.8	129.8	0	20.8
Gizzard Shad	0	0	0	0	12.7	0	1.9
Hybrid Striped Bass	0	0	0	0	3.9	0	0.6
Mooneye	0	3.0	0	0	2.0	0	0.7
Quillback	0	0	0	0	2.0	0	0.3
River Carpsucker	0	0	0	0	3.9	0	0.6
Walleye	0	0	0	0	2.0	0	0.3
Total	4.4	3.0	4.0	3.9	228.3	0	37.3

Early April 2002 session

	Habitat types						
	Island		Back	Main		Deep	
Species	Head	Tail	channel	channel	Trib	hole	Total
Channel Catfish	0	1.7	5.6	2.9	0	0	2.9
Emerald Shiner	0	0	0	0	1.5	0	0.1
Flathead Catfish	0	0	0	0.3	0	0	0.1
Freshwater Drum	0	0	0.6	0.3	21.4	0	2.2
Gizzard Shad	0	0	0	0	3.1	0	0.3
Highfin Carpsucker	0	0	0	0	3.1	0	0.3
Mooneye	0	0	0.6	0	0	0	0.1
River Carpsucker	0	0	0	0	6.1	0	0.6
Total	0	1.7	6.7	3.5	35.2	0	6.7

Mid-April 2002 Session

	Habitat types						
	Island		Back	Main		Deep	
Species	Head	Tail	channel	channel	Trib	hole	Total
Bluegill	0	0	0	0	1.7	0	0.2
Channel Catfish	7.1	1.8	2.1	2.2	13.1	0	3.6
Emerald Shiner	0	0	0	0	4.9	0	0.5
Freshwater Drum	5.3	3.5	1.4	0.4	14.8	0	2.8
Gizzard Shad	0	0	0	0.4	0	0	0.2
Mooneye	0	0	0	0.4	0	0	0.2
Orangespotted Sunfish	0	0	0	0	1.6	0	0.2
River Carpsucker	0	0	0	0	9.8	0	1.0
Total	12.4	5.3	3.5	3.3	46.0	0	8.5

February - April 2002 sessions total

	Habitat types						
	Island		Back	Main		Deep	
Species	Head	Tail	channel	channel	Trib	hole	Total
Bluegill	0	0	0	0	0.3	0	0.1
Channel catfish	4.1	1.9	3.8	2.1	25.8	0	5.8
Common carp	0	0	0	0	1.4	0	0.2
Emerald shiner	0	0	0	0	2.8	0	0.4
Flathead catfish	0	0	0	0.1	0	0	0.1
Freshwater drum	2.0	0.9	0.9	1.1	55.1	0	8.6
Gizzard shad	0	0	0	0.1	19.6	0	2.8
Highfin carpsucker	0	0	0	0	0.7	0	0.1
Hybrid striped bass	0	0	0	0	1.4	0	0.2
Mooneye	0	1.4	0.2	0.1	0.7	0	0.3
Orangespotted Sunfish	0	0	0	0	0.3	0	0.1
Quillback	0	0	0	0	0.7	0	0.1
River carpsucker	0	0	0	0	5.2	0	0.7
Walleye	0	0	0	0	1.0	0	0.1
Total	6.1	4.2	4.9	3.6	114.7	0	19.6

December 2002 session

	Habitat types							
	Island		Back	Main		Deep	Embay-	
Species	Head	Tail	channel	channel	Trib	hole	ment	Total
Black Crappie	0	0	0	0	0	0	1.8	0.1
Bluegill	0	0	0	0	0	0	198.3	13.1
Channel Catfish	0	0	2.6	7.0	0	2.7	0	3.2
Common Carp	0	0	0.4	0	0	0	0	0.1
Emerald Shiner	0	0	0	0	0	0	210.5	13.9
Freshwater Drum	0	1.0	5.6	10.4	0	8.2	7.0	6.1
Gizzard Shad	0	0	0	0.4	0	0	708.8	46.9
Green Sunfish	0	0	0	0	0	0	5.3	0.4
Mooneye	0	1.9	1.5	0	0	0	0	0.7
Mosquitofish	0	0	0	0	0	0	1.8	0.1
Ohio Lamprey	0	0	0.4	0	0	0	0	0.1
Orangespotted Sunfish	0	0	0	0	0	0	61.4	4.1
River Carpsucker	0	0	0	0.4	0	0	0	0.1
Sauger	0	1.0	0	0	0	0	0	0.1
Silver Chub	0	6.7	0.4	1.7	0	0	0	1.2
Smallmouth Buffalo	0	1.0	0.7	0.4	0	0	0	0.5
Spotted Bass	0	0	0	0	0	5.5	0	0.2
Spotted Sucker	0	0	0	0	0	0	1.8	0.1
Warmouth	0	0	0	0	0	0	3.5	0.2
White Bass	0	0	0.4	0	0	0	0	0.1
White Crappie	0	0	0	0	0	0	57.9	3.7
Total	0	11.4	11.9	20.2	0	16.4	1257.9	95.0

January 2003 session

	Habitat types						
	Island		Back	Main		Deep	
Species	Head	Tail	channel	channel	Trib	hole	Total
Black Buffalo	0	0	0	0	0	0	0.1
Black Crappie	0	0	0	0	0.9	0	0.1
Channel Catfish	0	0	1.1	1.3	6.4	0	1.6
Common Carp	0	1.4	0.7	0	1.8	0	0.7
Emerald Shiner	0	0	0	0	0	0	0.2
Freshwater Drum	0	0	1.8	3.0	50.9	0	8.7
Gizzard Shad	0	0	0.4	0	0.9	0	0.3
Golden Redhorse	0	0	0	0	0.9	0	0.1
Highfin Carpsucker	0	0	0	0	1.8	0	0.2
Hybrid Striped Bass	0	0	0	0	3.0	0	0.3
Mooneye	0	0	0	0.7	0	0	0.2
Quillback	0	0	0	0	0.9	0	0.1
River Carpsucker	0	0	0	0	3.6	0	0.6
Rock Bass	0	0	0.4	0	0	0	0.1
Sauger	0	0	0	0	0.9	0	0.1
Shorthead Redhorse	0	0	0	0.3	0	0	0.2
Silver Chub	0	0	0.4	0	0	0	0.1
Smallmouth Buffalo	0	0	1.4	1.0	24.5	0	5.2
White Bass	0	0	0	0.3	30.9	0	4.1
Total	0	1.4	6.0	6.7	127.3	0	23.1

March 2003 session

	Habitat types							
	Island		Back	Main		Deep	Embay-	
Species	Head	Tail	channel	channel	Trib	hole	ment	Total
Black Crappie	0	0	0	0	0	0	1.1	0.1
Bluegill	0	0	0	0	0	0	56.9	5.5
Bowfin	0	0	0	0	0	0	1.1	0.1
Channel Catfish	0	0	6.7	4.5	4.5	0	0.0	3.9
Common Carp	0	0	0	0.6	0	0	3.4	0.5
Emerald Shiner	0	0	0	0	0	0	19.0	1.8
Freshwater Drum	0	0	0.8	34.1	40.3	0	2.2	17.6
Gizzard Shad	0	0	0.4	3.5	1.5	0	29.0	4.3
Green Sunfish	0	0	0	0	0	0	4.5	0.4
Hybrid Striped Bass	0	0	0	1.9	5.2	0	0	1.4
Largemouth Bass	0	0	0	0	0	0	3.4	0.3
Mooneye	0	0	0.8	0.3	0	0	0	0.3
Orangespotted Sunfish	0	0	0	0	0	0	15.6	1.5
Pumpkinseed	0	0	0	0	0	0	5.6	0.5
Quillback	0	0	0	0	0.8	0	0	0.1
River Carpsucker	0	0	0.8	0.3	1.5	0	4.5	1.0
Sauger	0	0	0	0	0.8	0	0	0.1
Silver Chub	0	0	0.4	0.3	0	0	0	0.2
Smallmouth Buffalo	0	1.5	1.7	2.3	2.2	0	1.1	1.7
Spotted Sucker	0	0	0	0	0	0	1.1	0.1
Walleye	0	0	0	0	0.8	0	0	0.1
Warmouth	0	0	0	0	0	0	3.4	0.3
White Bass	1.6	0	0.8	1.0	2.2	0	0	1.0
White Crappie	0	0	0	0.3	0	0	41.3	4.1
Total	1.6	1.5	12.6	49.2	59.6	0	193.1	46.9

December 2002-March 2003 sessions total

	Habitat types								
	Island		Back	Main		Deep	Wing	Embay-	
Species	Head	Tail	channel	channel	Trib	hole	dam	ment	Total
Black Buffalo	0	0	0	0	0	0	7.5	0	0.04
Black Crappie	0	0	0	0	0.3	0	0	1.4	0.1
Bluegill	0	0	0	0	0	0	0	111.9	6.1
Bowfin	0	0	0	0	0	0	0	0.7	0.04
Channel Catfish	0	0	3.3	4.8	4.1	0.9	0	0	3.1
Common Carp	0	0.5	0.4	0.2	0.6	0	7.5	2.1	0.5
Emerald Shiner	0	0	0	0	0	0	15.0	93.5	5.2
Freshwater Drum	0	0.5	2.8	16.3	34.8	2.6	52.6	4.1	11.0
Gizzard Shad	0	0	0.3	1.3	1.0	0	7.5	293.3	16.7
Golden Redhorse	0	0	0	0	0.3	0	0	0	0.04
Green Sunfish	0	0	0	0	0	0	0	4.8	0.3
Highfin Carpsucker	0	0	0	0	0.6	0	0	0	0.1
Hybrid Striped Bass	0	0	0	0.7	3.2	0	0	0	0.6
Largemouth Bass	0	0	0	0.1	0	0	0	2.1	0.2
Mooneye	0	0.9	0.8	0.3	0	0	0	0	0.4
Mosquitofish	0	0	0	0	0	0	0	0.7	0.04
Ohio Lamprey	0	0	0.1	0	0	0	0	0	0.04
Orangespotted Sunfish	0	0	0	0	0	0	0	33.4	1.8
Pumpkinseed	0	0	0	0	0	0	0	3.4	0.2
Quillback	0	0	0	0	0.6	0	0	0	0.1
River Carpsucker	0	0	0.3	0.2	1.9	0	7.5	2.7	0.6
Rock Bass	0	0	0.1	0	0	0	0	0	0.04
Sauger	0	0.5	0	0	0.6	0	0	0	0.1
Shorthead Redhorse	0	0	0	0.1	0	0	7.5	0	0.1
Silver Chub	0	1.8	0.5	0.7	0	0	0	0	0.5
Smallmouth Buffalo	0	0.9	1.3	1.3	9.5	0	90.2	0.7	2.5
Spotted Bass	0	0	0	0	0	1.7	0	0	0.1
Spotted Sucker	0	0	0	0	0	0	0	1.4	0.1
Walleye	0	0	0	0	0.3	0	0	0	0.04
Warmouth	0	0	0	0	0	0	0	3.4	0.2
White Bass	0.5	0	0.4	0.4	11.7	0	7.5	0	1.7
White Crappie	0	0	0	0.1	0	0	0	47.8	2.6
Total	0.5	5.0	10.1	26.6	69.6	5.2	203.0	607.1	54.9

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PRESENTATIONS

Lenz, B., S. Welsh, K. Hartman. Winter habitats of fishes in the Ohio River. Presented at the American Fisheries Society annual meeting, Quebec City, Canada, 12 August 2003.

Lenz, B., S. Welsh, K. Hartman. Winter habitats of fishes in the Belleville Pool, Ohio River. Presented at the West Virginia Cooperative Fish and Wildlife Unit annual meeting, Morgantown, WV, 24 April 2003.

Lenz, B., S. Welsh, K. Hartman. Winter habitats of channel catfish and freshwater drum in the Belleville Pool, Ohio River. Presented at the Wildlife Society annual meeting, Morgantown, WV, 6 March 2003.

Lenz, B., S. Welsh, K. Hartman. Winter habitats of channel catfish and freshwater drum in the Belleville Pool, Ohio River. Presented at the Tri-State (Kentucky, Virginia and West Virginia) annual meeting, Ashland, KY, 5 March 2003.

Lenz, B., S. Welsh, K. Hartman. Winter habitats of channel catfish and freshwater drum in the Belleville Pool, Ohio River. Presented at the Southern Division of the American Fisheries Society annual meeting, Wilmington, NC, 16 February 2003.

FIELDS OF STUDY

Major Field: Zoology

Specialization: Aquatic Ecology

Final Report

Ohio River Mainstem System Study

(ORMSS)

Fish Passage Issues Associated with Ohio River High-Lift Dams

Submitted To:

U.S. Army Corps of Engineers
Huntington District
Huntington, West Virginia

Submitted By:

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April 2004

Study Abstract

The Ohio River and its major tributaries have played a key role in the development of North America by European settlers. From its origins in the northern Appalachian Mountains to its confluence with the Mississippi River, the river has and continues to provide both habitat for diverse aquatic life, as well as resources for the human inhabitants. Since its initial canalization in the early 1880s to the completion of high-lift locks and dam complexes in the late 1990s, the river has been altered from a dynamic lotic ecosystem to more controlled series of navigational pools. Recently, all river users associated with both environmental and navigational issues have expressed concern over the river's condition.

To address these diverse issues, the Ohio River Mainstem System Study (ORMSS) was proposed with an overall goal to determine the optimum investment strategy for major navigation improvements along the entire length of the Ohio River. Since its inception, the ORMSS has evolved to address both economic and environmental concerns associated with navigation and improvements. The findings reported herein are concerned with these environmental issues associated with fish passage.

Several collaborative studies were conducted over a three-year period to determine the influence of high-lift dams on fish passage.

Major findings were:

a. Migratory fish species do congregate seasonally downstream of locks and dam complexes,
b. If river conditions are suitable, Ohio River fish do move through locks and dam complexes,
c. Distinct sub-populations exist between both downstream and upstream reaches, and
d. Minimal interactions between upper and lower river fish occur.

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Chapter 1

Ohio River Mainstem System Study (ORMSS)

Project Overview and Synthesis of Results

Introduction

The Ohio River is one of the great rivers of North America. From its origins in the northern Appalachian Mountains of New York, Pennsylvania, and West Virginia to its confluence with the Mississippi River, the Ohio River provides a diverse ecosystem for both humans and aquatic life. Native Americans utilized the Ohio River for transportation via bark and dugout canoes, as well as sources of fish and game for food. Europeans first visited the Ohio in the 1540s with the overland expedition by DeSoto from Florida through the Tennessee and Cumberland rivers sub-basins and into the lower Ohio River system. In the late 1600s, notable explorers such as LaSalle and Arnout Viele descended the Ohio River via its major tributary, the Allegheny River. Abraham Wood between 1654 and 1664 explored the north-flowing major tributaries such as the New and Kanawha rivers. With the initiation of conflicts between Great Britain and France over North American superiority, the Ohio River became a key area of contention. French forts at current day Pittsburgh near the confluence of the Allegheny and Monongahela rivers were seen by the British as an encroachment to their sovereignty resulting in a force lead by Major George Washington of Virginia to attack French installations. This battle won by the French precipitated the French and Indian War leading to the temporary dominance of North America by the British.

The Ohio River also played a key role during the American Revolution. General George Rogers Clark successfully directed a force into the lower Ohio River sub-basin that lead to the American claims of ownership of the Northwest Terrorist. Following the American Revolutionary War, thousand of settlers floated down the Ohio River from Pittsburgh and Wheeling, as well as Oleans on the Allegheny River and Kelly's Station on the Kanawha River. River cities like Marietta, Cincinnati, and Louisville soon were formed leading to the admission of Kentucky (1792) and Ohio (1803) into Union. In 1803, Meriwether Lewis and William Clark set out from present day Pittsburgh and floated down the Ohio River to Camp Wood at the mouth of the Missouri River to set our on their historic Corps of Discovery.

The influx of settlers into the Ohio River basin resulted in this region becoming a dominant center for industry and enterprise. Boat building, and mining for coal and iron ore provided an infant steel and iron industry to flourish. Glassmaking also become established by the start of the 1800s. With this expanding industrial economy, the need for transportation was evident. Early river transportation was primarily through the use of flatboats, keelboats, and barges that moved cargo downstream. Keelboats also provided regular passenger service between Louisville, Cincinnati, and Pittsburgh. In 1811, the first steamboat, the *New Orleans*, was first to navigate the Ohio River marking the inception of modern day travel. Steamboats were the primary mode of river-based transportation of both cargo and passengers until the advent of diesel powered towboats.

The emergence of the Ohio River as a vital route of commerce resulted in the need for navigational-associated improvements. In a retrospective description of the Ohio River by the Chief of Engineers in 1934, the system was considered obstructed

throughout its entire length by snags, rocks, and gravel and sand bars. Channel width and depth was variable with depths at a minimum of 1-foot over shallow shoals. This resulted in the impedance of commercial navigation. Flooding also was considered a hazard to commercial navigation. In 1824 with the passage of the Inland Waterways Improvement Act, the U.S. Army Corps of Engineers (USACOE) was directed to determine the best method with coping with sandbars and snags. Soon after, the USACOE initiated a process to tame the river that continues to the present day.

Early attempts to improve navigation were concentrated on the removal of snags and other obstructions, as well as the use of cutoff dams to concentrate flow in the main channel. Construction of the first cutoff dam began in 1825, and the first removal of rocks was begun in 1830. These activities continued until the 1870s when activities were initiated to build lock and dam complexes. In 1875, it was recommended that 13 locks and removable dams be constructed on the Ohio River between Pittsburgh and Wheeling. The first of these complexes was the Davis Island Dam near Pittsburgh that was completed in 1885. The construction of 51 removable dams and associated locks resulting in the canalization of the Ohio River was completed with four complexes by 1929 in the lower reaches of the river. These dams provided commercial navigation a continuous 9-foot channel along the 981-mile length of the Ohio River.

The replacement of these removable dams with fixed high-lift structures was initiated in 1932 with the construction of the Montgomery Locks and Dam complex downstream of Pittsburgh. These high-lift structures included a dam across the entire river with vertical-lift gated spillways, and a main and auxiliary lock chamber. A navigation pool upstream of the locks and dam complex resulted in the alteration of the

Ohio River from a lotic to lenthic system. Only those reaches just downstream of these high-lift dams remained in a lotic state.

Since 1932, 17 additional high-lift locks and dam complexes have been constructed replacing 49 of the 51 removable dams. Two removable dams are still in operation in the lower reach of the system. Consequently, the 981-mile long Ohio River is primarily a series of navigation pools with free-flowing tailwaters downstream for a few miles of these high-lift dams. Most large tributaries have been changed with the construction of flood control dams and/or navigational locks and dams further altering the hydrology of this 204,000 square-mile basin. This has resulted in a very different Ohio River basin as what was first discovered by early European explorers.

The advent of modern navigation on the Ohio River presents many potential influences on aquatic life. Modern towboat propellers cause immediate alterations in hydraulic patterns and increased turbulence as they pass through the water column (Maynord 1990). Cada (1990) reported that fish eggs and larvae experience stress after passage through water currents induced by propellers. Fish at early life stages are more susceptible to propeller impacts because of their delicate condition and lack of avoidance mechanism (Pearson et al. 1989). Elevated mortality of eggs and larvae may result in decreased adult recruitment especially for pelagic species inhabiting main channel reaches (Holland and Sylvester 1983). Mortality of ichthyoplankton related to propeller type turbine passage has been reported as low as 5 percent (Cada 1990). Minimal mortality also has been reported in control studies investigating pressure changes and rapid acceleration (Payne et al. 1990). Sheer forces along a barge hull have been reported sufficient to kill larval fishes (Morgan et al. 1976) and sheer forces associated with

propellers are substantially greater than that associated with barge hulls. Kilgore et al. (2001) did report larval fish mortality approaching 75% associated with propeller based sheer forces for several Mississippi River species.

Another aspect is the passage of migratory fish species through locks and dam complexes. With the construction and operation of the 18 high-lift structures and the proposed replacement of the last two removable dams with a high-lift structure, concern was expressed as to the impact of these structures on fish passage within the Ohio River sub-basin. Truly great river species such as paddlefish and shovelnose sturgeon inhabit the Ohio River main channel as well as species such as sauger, walleye, white bass, and several species of clupeids that exhibit migratory behavior (Etnier and Starnes 1993). In addition, several unionid species depend on species of migratory fish species to serve as host in the reproduction process. Consequently, fish passage through large navigational lock and dam complexes was proposed as a concern within the Ohio River sub-basin (USACOE 2000). A major direction of the study described herein was related with fish passage issues.

Lotic reaches downstream of high-lift dams are the last vestiges of the once free following Ohio River. At most high-lift dams, tailwaters exist downstream for a 2-5 mile reach providing both aquatic biota and humans a fairly unique lotic environment. These tailwaters are often used by fish as spawning areas and many species congregate in these tailwaters during the late winter and spring. Unionid species also are more abundant in these tailwaters resulting in the potential for host relationships with fish species. Lastly, anglers seek many migratory fish species in the winter and spring, as well as catfish species in the summer in these oxygen-rich reaches.

USACOE (2000) outlined needs and goals of the Ohio River Mainstem System Study (ORMSS). Initially, the ORMSS was an overall system study to determine the optimum investment strategy for major navigation improvements along the entire length of the Ohio River. Since its inception, the ORMSS has evolved to address both economic and environmental concerns associated with navigation and improvements. This study is part of the ORMSS process in addressing recreational use by anglers of tailwater reaches and fish passage issues. A complimentary study was conducted addressing winter habitat use by fish in two Ohio River navigational pools.

***The goals of this study were*:**

1. To assess recreational angling activities at high-use tailwater reaches created by these locks and dam complexes,
2. To determine host relationships between unionids and fish species, and
3. To provide insight into fish passage concerns of selected species.

More detailed discussions of each component are provided in associated chapters. This project overview was designed to provide a synopsis of the study components.

Recreational Angling Use:

Ohio River angling opportunities are diverse both in species sought and habitat available. Major recreational fisheries exist for sauger, walleye, white bass, hybrid striped bass, as well as the catfishes and the black basses. Open river sections, embayments and backwaters, as well as tailwaters provide habitat for both anglers and fishes. Schell et al. (1996) reported that tailwaters comprise only 1% of available angling habitat in the Ohio River, but generated more than 66% of the total catch.

To assess angling-based recreation, surveys were conducted at eight tailwaters for a minimum of 12 months. A modified bus-stop method was employed at most tailwaters

were more than one access site was present (Jones and Robson 1991). Surveys were conducted either on foot at access sites or via boat where access was limited. Boat surveys were conducted primarily at the J.T. Myers and New Cumberland tailwaters. Surveys were conducted three days per week (1 weekend period and 2 weekday periods) to determine angler directed effort, catch, harvest, and effort. The ORFMT state agencies developed survey forms that were consistent with past investigations (Schell et al. 1996; Pierce et al. 1983). Count times were randomly assigned at four 15-minute intervals per day. These data were used to estimate total angling effort in hours.

Data were recorded on paper copy, entered using a standard data entry format, and subjected to a QA/QC procedure. Once approved, data were analyzed by the Ohio Division of Wildlife Inland Fisheries Research Group using a SAS-based analytical package with the methods described in Pollock et el. (1994). Results were reported as catch rate (no./hr), effort (hours), and directed effort (%), and length of harvested individuals (mm; total length except for paddlefish which was recorded as eye-fork length).

Interviews were conducted on over 8,500 angler-trips at the eight tailwaters. Anglers resided primarily within the bordering states adjacent to the tailwaters. The predominance of resident anglers usually was a function of better access in these tailwaters.

Directed effort groups were dominated by any species (33%) and percids (24%) river-wide. Catfish (17%), *Morone* species (16%), paddlefish (10%), and black bass (1%) were represented. The any species group and percid group dominated most upstream tailwaters, and catfish were of greater importance in downstream tailwaters. Paddlefish

were of greatest importance at the Markland tailwater with 43% of the effort being expended on this group. The Greenup tailwater fishery was dominated by *Morone*-seeking anglers (44%).

Angling effort peaked in the June-August period (catfish-associated angling) for all tailwaters. A second peak was evident in the late-fall and was most likely associated with the percid and *Morone* fishery. Tailwaters comparisons were made only for the February 2002 through September 2002 period. The McAlpine and Willow Island tailwaters had the greatest angling effort during this period with hours of 19,969 and 15,917 respectively. Angling hours also exceeded 10,000 for the Greenup, Markland, J.T. Myers, and R.C. Byrd tailwaters. Proximity to more urban areas and improved availability of access may have be a factor in increased effort.

Catch rates by directed species group were determined for sauger, all percids (sauger, saugeye, walleye), hybrid striped bass, white bass, and channel catfish by tailwaters. Sauger catch rates ranged from 1.86/hr for the Pike Island tailwater to 0.22/hr for the Markland tailwater. Total percid catch rates ranged from 1.89/hr for the Pike Island tailwater to 0.22/hr for the Markland tailwater. In the Markland, McAlpine, and J.T. Myers tailwaters, the percid fishery was dominated (>98%) by sauger. Hybrid striped bass catch rates were greatest at the Greenup tailwater (1.64/hr) and least at the R.C. Byrd tailwater (0.19/hr). White bass catch rates were dissimilar with catch rates exceeding 0.75/hr at the Pike Island tailwater (1.28/hr), R.C. Byrd tailwater (0.88/hr), and Willow Island tailwater (0.79/hr). Channel catfish catch rates were greatest at the J.T. Myers tailwater (0.68/hr) and lowest at the Willow Island tailwater (0.04/hr). Paddlefish were only caught at the J.T. Myers and Markland tailwaters in adequate numbers to determine

catch rates. Paddlefish catch rate at the Markland tailwater was 0.20 and 0.19/hr. at the J.T. Myers tailwater. Harvest of paddlefish is prohibited from reaches of the Ohio River bordering the states of West Virginia and Ohio.

Sauger, hybrid striped bass, and white bass were the dominant species caught with over 20,000 caught river-wide. An estimated 2,064 paddlefish were caught at all Ohio River tailwaters of which 92% of the paddlefish caught were harvested. The majority of paddlefish were caught at the Markland tailwater (867-99% harvested) and J.T. Myers tailwater (967-99% harvested). Percent harvested ranged from 92% for paddlefish to 3% for hybrid striped bass. River-wide 34% of sauger, 13% of white bass, 31% of channel catfish and 77% of blue catfish were harvested.

Ohio River tailwater-anglers sought primarily those species related to tailwater habitats. Geographic differences of directed effort were evident with the upstream tailwater fisheries dominated by any species and percid groups, the Greenup tailwater by the *Morone* sp. group, and the J.T. Myers tailwater dominated by catfish group. Interest in these fisheries may be a factor of culture, abundance of a given fish species, and the presence or perception of a consumption advisory or health risk. Catfish angling is of greater importance in mid-west and southern states (USFWS 2003, Burlingame and Guy 1999, TVA 1998). Both blue and channel catfish are present in downstream Ohio River tailwaters, and are often extremely abundant. Consumption advisories have and continue to be present in the upper Ohio River (WVDNR 2004). The importance of percids and *Morone* species in upstream tailwaters is partially the result of the abundance of these species, the hydrologic conditions at locks and dam complexes that congregate these species, and the overall cultural importance of angling and the seasonal trends of these

fisheries. Paddlefish were only sought at the J.T. Myers and Markland tailwaters. Directed paddlefish angling is prohibited in the Ohio-West Virginia reach of the Ohio River (WVDNR 2004). The Markland tailwater historically has been popular for paddlefish angling, and hydrologic conditions at this locks and dam complex congregate this species (Henley et al. 2002).

Channel catfish catch rates were greatest at the J.T. Myers tailwater (0.68/hr) and lowest at the Willow Island tailwater (0.04/hr). Catch rates reported from the Missouri River (0.13.hr) and the Tennessee River-Watts Bar tailwater 0.02/hr) were within this range (Stanovick 1999; TVA 1998). Ohio River tailwater catch rates exceeded that found from the Tennessee River-Watts Bar tailwater for all major sport fish species.

Percent of fish harvested was lowest in upstream Ohio River tailwaters. Sauger, walleye, largemouth bass, white bass, hybrid striped bass, catfish species, freshwater drum, and common carp all have consumption advisories in the West Virginia-Ohio reach of the Ohio River (WVDNR 2004).

Present study angling effort was greatly reduced as compared to previous surveys Pierce et al. (1983), Schell et al. (1996), and ORFMT (2001). A reduction of over 50% was estimated for the New Cumberland, Pike Island, Willow Island, Greenup, and Markland tailwaters, as well as 90% at the Greenup tailwater. Water levels were considerably higher in 2002 than 2000 resulting in loss of angling days. Homeland security issues following the September 11, 2001 events resulted in the temporary closure of several access points at Ohio River locks and dam complexes. In addition, a popular access area in the Greenup tailwater was closed from September 2001 through May 2002.

Access appeared to be one factor contributing to angler use and angler residence. Better access is afforded on the Ohio bank at the Pike Island and New Cumberland tailwaters, resulting in a greater percentage of Ohio residing anglers. In contrast, angler access is easier on the West Virginia bank at the Willow Island tailwater, consequently a higher percent of West Virginia anglers fished this tailwater. At tailwaters where easy access is on both banks, angler use by residence was similar. Tailwaters with better or more reliable access were used to a greater degree by anglers than those tailwaters with poor access.

Recreational angling in the Ohio River is of great importance. Over 5.5 million anglers within the six Ohio River bordering states fished in 2001 spending over $ 15.00 per trip (USFWS 2003). Tailwaters created by USACOE high-lift dams are of particular importance with over 65% of the angling effort being expended in these limited reaches Schell et al. (1996). Although several natural and stochastic factors may and will continue to influence angling effort and therefore economic impact of this important activity, increased and improved access to these reaches is one issue that can be addressed. Access by both boat and shore anglers will provide greater angling opportunities resulting in both citizen enjoyment and awareness of the Ohio River, as well as economic benefits to local communities.

Presence of Glochidial Infestation on Ohio River Fish Species:

Freshwater mussels exhibit a highly specialized life history. Modified larvae, glochidia, experience a period as an obligate parasite on the gills, fins, and potentially other external structures of fish. Released glochidia must encounter a suitable fish host, become encysted for a period of time while metamorphosing into juvenile mussels, and

finally release from the fish host. If suitable fish hosts are not encountered, glochidia will be rejected (Kat 1984). Knowledge of fish host and infestation rates is essential in the conservation of North American mussel fauna (Haag and Warren 1997).

The decline of the North American freshwater mussel fauna is well-documented (Williams et al. 1993). Dams, through altering flow regimes, have caused the extirpation of 30%-60% of the native mussel species in selected United States rivers (Williams et al. 1992). Competition from expanding non-endemic mollusks populations has also lead to the decline in native mussel fauna. These range extensions have often been linked to commercial navigation uses.

Concern for native freshwater mussel populations in the Ohio River sub-basin and the potential influence of commercial navigation and locks and dam complexes lead to the investigation of infestation of potential fish hosts, and the problems associated with fish passage.

Fish were collected from 10 different locations within the Ohio River. The J.T. Myers tailwater (ORM 850) represented the most downstream location and the most upstream location was the New Cumberland tailwater (ORM 55). Most collections were made in tailwater reaches because of the potential presence of freshwater mussels in these free-flowing sections, and the congregation of fish species just downstream of the locks and dam complexes. One collection in the Belleville Pool was at the vicinity at a known historic unionid bed.

Thirty-one fish species were collected representing a wide range of behavioral and habitat guilds. Common large river species included the gizzard shad, freshwater drum, redhorses, sauger, and white bass. Non-endemic species included the grass carp,

common carp, saugeye, and hybrid striped bass. Uncommon species included the blue sucker and goldeye. One-thousand and sixty-seven individuals were processed (identified, measured, and dissected). Of these, 536 were examined for the presence of glochidia. All samples taken in the winter and spring were examined, as were 64% of the summer samples, and 42% of the fall samples. Only gizzard shad (84 of 307, 27%) were examined at a less than the 40% criteria of common species.

Four fish (<1%) were found to be infested with glochidia. These included three individuals from the R.C. Byrd tailwater collection in June 2002 and one individual from the J.T. Myers tailwater collection in October 2002. Longnose gar, gizzard shad, and skipjack herring from the R.C. Byrd tailwater collection, as well as a spotted bass from the J.T. Myers tailwater were infested.

The low infestation rates were similar to those found in several river systems including the Green River, a major tributary to the Ohio River (Weiss and Layzer 1995). Glochidia were found in both the spring (June) and fall (October). Several investigators have reported the presence of glochidia infested on fish during all seasons, as well as the presence of glochidia in the water column (Jansen 1991, Weiss and Layzer 1995, Neeves and Widlak 1988). In addition, the fish species found to be infested in this study have been found to serve as hosts (Haag and Warren 1997). Longnose gar, gizzard shad, skipjack herring, and spotted bass also have been reported to serve as host for species of Ohio River mussels (OSU Division of Mollusks-Host Database).

The presence of glochidia in free ranging fishes is problematic because of the natural low rate of infestation. If fish passage issues do exist in relation to glochidia infestation and leading to the decline of unionid populations, it is suggested that a more

informative approach may be the modeling of potential fish hosts and their association with high-lift dams and passage mechanisms.

Fish Movement and Passage through High Lift Dams:

Fish passage issues related to locks and dam complexes are well documented for salmonid fish species (Bergkamp et al. 2000), but impacts to warmwater species are not as well documented. Pearson and Pearson (1989) stated that the elimination of Alabama shad in the Ohio River sub-basin was partially attributed to impaired movement due to high lift dams. Pallid and shovelnose sturgeon populations have been impacted in part by habitat alterations associated with navigation (Keenlyne 1987). Atlantic shad populations also have been adversely affected in rivers impaired by dams (Rulifson 1994), but attempts to pass this species via locking have been fairly successful (Bailey et al. 2004). Other studies suggest that passage may be related to retention time in the proximity to a passage facility (Barry and Kynard 1986), and/or the time spent in a tailwater reach (Pegg et al. 1997). Consequently, factors influencing the passage of most fish species are not well understood and potentially could be a factor in a species decline.

To better understand fish passage in the Ohio River, three complimentary studies were conducted. First, a tagging study of percids, white bass, and paddlefish was conducted throughout the sub-basin. Sauger, saugeye, walleye, and white bass were collected using pulsed DC boat-mounted electrofishing gear during the Fall 2001, as well as Winter, Spring, Fall 2002 and Winter 2003; and tagged with color-coded, uniquely numbered T-Bar anchor tags. Paddlefish were collected by ORFMT biologists and project staff, as well as commercial fishers using variable size (length x width) gill nets consisting of a single panel of 127mm square-bar mesh, as well as pulsed DC boat-

mounted electrofishing gear. Sampling was conducted during the Fall (2001 and 2002), Winter (2002 and 2003), and Spring (2002 and 2003). Paddlefish were checked for the presence of a coded-wire tag (CWT), jaw tag, or elastomer mark. Individuals were then measured (eye-fork length) and inserted with a metal jaw tags prior to release. Jaw tags were uniquely numbered and information concerning mailing address and rewards were present.

Anglers reported the capture of tagged percid and white bass via mail, telephone, or e-mail. Paddlefish tag returns were primarily acquired from commercial fishers, and rewards were provided by the Kentucky Department of Fish and Wildlife (KDFW). An additional effort to collect paddlefish information was conducted through a creel survey conducted by the KDFW in the lower open section of the river, as well as in the lower Tennessee River downstream of Kentucky dam. Project creel surveys also collected tags form all species.

Movement was ascertained for all recaptured fish if information was available. Movement was determined by location (i.e. pool tagged) and direction was noted as either upstream, downstream, or no movement (recaptured within the tagging pool). The number of locks and dam complexes traversed was determined. Gage stage and discharge information were acquired from USGS database (USGS 2003). Water levels at specific locks and dam complexes were acquired from the U.S. Army Corps of Engineers District offices and elevations between upstream and downstream points (head differential) at locks and dam complexes were ascertained by subtracting the downstream elevation from the upstream elevation.

A second approach was to intensively study several species of fish over a limited time period. An investigation at the Winfield Locks and Dam complex (Kanawha River KRM 31.1) was conducted to determine if the fish community inhabiting lock chambers were representative of tailwater reaches. A second phase was to determine short-term movement patterns of targeted species at this complex. Intensive fish sampling tasks were conducted from 19 May 2003 through 29 July 2003. Six fish species were selected to represent large river fishes occupying different behavior and habitat guilds. These species were collected using a variety of techniques and either tagged (t-bar) or marked (elastomer) for future identification.

A final study was conducted using fatty acid composition analysis. Samples from sauger, white bass, and paddlefish were collected from the following pools: Hannibal, Belleville, Greenup, Meldahl, Cannelton, and Smithland. Data for thirteen fatty acids and for total percent lipids were measured. Lipids were extracted from the white muscle tissue. Fatty acids were analyzed by gas chromatography and flame ionization detection with confirmation by gas chromatography—mass spectrometry.

Sauger (5,554), saugeye (53), walleye (432), and white bass (595) were tagged at nine tailwater locations within the Ohio River sub-basin. Anglers recaptured 559 (10%) sauger, 9 (17%) saugeye, 52 (12%) walleye and 52 (9%) white bass. In addition, 51 tagged-sauger and 3 tagged-walleye were recovered during scientific-based surveys.

Ninety percent (90%) of the sauger was recovered within the Ohio River proper with the remaining being recovered within Ohio River tributaries. No sauger were reported from outside the Ohio River sub-basin. River-wide, 53% of the tagged sauger reported by anglers from the Ohio River proper displayed no movement (recovered

within the tagged-pool), 1% displayed a downstream movement, and 46% displayed upstream movement. Saugeye and walleye displayed a greater affinity not to move (78% of saugeye and 74% of walleye), and neither species were reported from downstream pools. Sauger moved into a few larger tributaries including the Wabash, Kentucky, Kanawha, and Allegheny rivers, but most sauger captured within a tributary river did display an affinity for an adjacent river either entering the tagged-pool of a tributary entering a pool just upstream of the tagged-pool. Geographically, sauger moved in a greater proportion to the tagged population from the Smithland Pool (through J.T. Myers Locks and Dam complex) and Greenup Pool (through R.C. Byrd Locks and Dam complex). Most upstream tagged sauger showed minimal affinity to move outside of the tagged pool.

Sixty-five percent of the recovered white bass displayed no movement, 2% displaying a downstream movement pattern, and 33% displaying an upstream pattern. White bass moved in a greater proportion to the tagged population from the Smithland Pool(through the J.T. Myers Locks and Dam complex) and Greenup Pool (through the R.C. Byrd Locks and Dam complex).

Downstream-tagged sauger and white bass (J.T. Myers to McAlpine complexes) moved between pools at greater rate than upstream-tagged (upstream of Racine complex) fish suggesting river conditions differed. Sauger were recovered within 20 days following tagging upstream of downstream locks and dam complexes in contrast to upstream-tagged sauger. For these individuals the first sauger reported upstream of a locks and dam complex was at 60 days following tagging and only after a high flow event which resulted in a head differential of less than 5-feet. This suggested that sauger

although having the opportunity to move through a lock, did not readily use this avenue. The J.T. Myers Locks and Dam complex does afford an auxiliary avenue with a canal open for fish movement when river stage is at least attainable throughout the year.

An evaluation of head differential at the Willow Island Locks and Dam complex provided some insight into the operational opportunities for fish passage. During the study period the upper Ohio River sub-basin experienced greater than average precipitation resulting in above average river stages. Consequently, on several occasions, head differential approached equilibrium at upstream high-lift dams. During one period (December 2001 through March 2002,) fish were tagged during typical river stages (December 16-20, 2001) and recovered by anglers soon afterwards. Interestingly, fish were not recovered upstream of the Willow Island complex until an atypical event resulted in head differential approaching equilibrium. In December 2002 through March 2003 similar conditions were evident and the tagging schemes provided similar results.

The influence of river stage and movement patterns was evident. All species moved through the R.C. Byrd Lock and Dam complex at a greater rate (63%) as compared to other mid-Ohio River lock and dam complexes (Belleville=22% and Willow Island=30%). River stage equilibrium (5-foot differential) was achieved 9.4% of the time at the R.C. Byrd Lock and Dam complex during the study period as compared to 1.4 % for the Belleville Lock and Dam complex and 1.6% for the Willow Island Lock and Dam complex.

Paddlefish were collected primarily in the more downstream reaches of the Ohio River because of the greater abundance of the species in this section. No paddlefish were collected upstream of the Willow Island Locks and Dam complex, although considerable

effort was expended in this reach. ORFMT and project biologists handled 1,579 paddlefish during the 29-month study period. An additional 6,430 were examined by a complimentary study conducted by the KDFW.

Six percent of the paddlefish handled by biologists had been inserted with CWTs, and less than 1% (24 of 6,430) handled by KDFW creel clerks. Jaw tags were inserted into 1,488 paddlefish during the project period. Jaw tags were recovered from 61 paddlefish (1%) of biologists collected paddlefish. Project clerks at the J.T. Myers, McAlpine, Markland, and Greenup tailwaters recovered no jaw-tagged paddlefish, although over 300 paddlefish were examined.

Movement patterns of recovered paddlefish were provided for 210 of 227 individuals. Paddlefish recovered from the Ohio River proper displayed no affinity for either downstream, upstream or no inter-pool movement. Fifty percent were recaptured within their tagging pool, 22% moved downstream, and 28% moved upstream. Downstream movement was slightly biased because more paddlefish were tagged in the extreme downstream pools. Paddlefish tagged in upstream pools (Greenup, Racine, and Belleville pools) displayed no inter-pool movement, as did extremely small (less than 400mm). Paddlefish were recovered from the Green, Tennessee, and Wabash river systems. These major Ohio River tributaries were adjacent to pools in which these paddlefish were tagged. Eight paddlefish tagged within the Ohio River sub-basin were recovered from outside of the sub-basin. One fish was recovered from the Illinois River, one from the Missouri River, and six from the Mississippi River.

Fish species composition was determined from the tailwater reach and the lock chamber at the Winfield Locks and Dam complex. Common species to both habitats were

gizzard shad, the minnows and shiners (ghost shiner, emerald shiner, and channel shiner), and freshwater drum. Species more common in tailwater habitats were white bass, skipjack herring, and sauger. Channel catfish, the sunfishes (*Lepomis* and *Pomoxis*), as well as hybrid striped bass were more common in lock chamber habitats. Species such as some of the catostomids and centrarchids were fairly uncommon in both types of habitats.

More migratory species appeared to occupy both habitat types, but to a differing abundance. Abundant migratory species in the lock chamber habitat included hybrid striped bass and gizzard shad. White bass, sauger, and gizzard shad, all migratory species, were more common in the tailwater sections.

Hybrid striped bass, sauger, smallmouth buffalo, skipjack, freshwater drum, and channel catfish were selected as study species on based abundance and migratory behavior. One-hundred and thirty-eight hybrid striped bass were tagged with T-bar anchor tags on six occasions within 15-days. The majority of these fish were tagged and released on 20 May, 22 May, 27 May, and 28 May. Investigators recovered 4 (3%) tagged individuals within the first 15 days following tagging, but no fish were recovered using electrofishing techniques after 4 June, nor were any fish recovered from outside of the Winfield Tailwater. Anglers caught 15 (11%) of the tagged hybrid striped bass. Twelve recaptured hybrid striped bass were caught from either the R.C. Byrd Pool (Winfield Tailwater, Kanawha River, or the Racine Tailwater, two from the Racine Pool (Belleville Tailwater), and no recapture location was reported for one individual. No hybrid striped bass displayed an upstream movement pattern through the Winfield Locks and Dam complex. Two 20 May tagged-fish were reported captured within 5-days of

tagging. Both individuals were caught in the Winfield Tailwater adjacent to the hydropower unit discharge.

Sauger, channel catfish, smallmouth buffalo, and freshwater drum were inserted with either yellow, red, or green elastomer in either the caudal, pelvic, or pectoral fins. Seventy-nine sauger, 81 smallmouth buffalo, 120 skipjack herring, 150 freshwater drum, and 120 channel catfish were inserted during May-June 2003. Recovery tasks were conducted for a period through 29 July 2003.

No marked skipjack herring were recovered during the study period. Twelve sauger (15%) were recovered from the Winfield Tailwater within 10 days of marking. No sauger were recovered after 2 June or from locations outside of the Winfield Tailwater. Channel catfish (15 of 120-12%), smallmouth buffalo (3 of 81-4%), and freshwater drum (9 of 150-6%) were recovered only from the Winfield Tailwater within 10 days of marking.

Paddlefish, white bass, and sauger were analyzed for lipid and fatty acid composition to assess population differentiation as a potential result of locks and dams. One hundred and twenty-one individuals were initially collected and analyzed from throughout the Ohio River proper. Data for thirteen fatty acids and for total percent lipids were measured.

There was no significant difference ($\alpha = 0.05$) among the mean percent lipids for sauger among the pools sampled. For white bass, percent lipids for the Meldahl Pool were significantly higher than for the Belleville or Greenup pools, with the data for Hannibal, Cannelton, and Smithland pools occurring intermediately.

The profiles for 13 fatty acids were compared between species and among locations. The mass balances for weight percent of fatty acids for Belleville data were determined to be unacceptable relative to all other locations. The data indicated that co-extracted interferences were found in the chemical results for Belleville for both sauger and white bass. In order to overcome this obstacle to data analysis, and produce data for Belleville Pool that could reasonably be compared to the other locations, the data for 11 selected fatty acids was reprocessed to assess the relative contribution of each identified fatty acid while excluding the interferences.

Using statistical procedures for analysis of variance and principal component analysis, the reprocessed data for fish collected in October was used to demonstrate (a) that fish species were separately identifiable within location using the fatty acid profile and (b) that as a biological marker the fatty acid profile indicated the existence of two distinct sub-populations, roughly separated into the upper and lower Ohio River reaches, for both sauger and white bass. These data strongly suggest that an effect of high-lift dam structure on fish movement was evident in the Ohio River.

Results from the three studies concerned with fish passage, as well as the recreational angling survey, suggest that although fish do pass through locks and dam complexes several factors may be inhibiting their movement. Tagging data of recovered percids and white bass indicated that greater than 55% of recovered fish displayed no movement through locks and dam complexes. Movement through these complexes was greater at downstream complexes, as compared to upstream complexes. Inter-pool movement also was primarily in an upstream direction with less than 5% displaying inter-pool movement in a downstream direction. When inter-pool movement was evident at

upstream complexes, it was in conjunction with extremely high river levels resulting in a near equilibrium in head differential at a given high-lift dam. Tag recovery data of paddlefish also suggest that this great river species displayed some inter-pool movement (approximately 50% of tagged-fish). Inter-pool movement in upstream and downstream directions was similar, but this was only evident in lower river pools. No paddlefish tagged and/or recovered in upper river pools displayed inter-pool movement. Data derived from fatty acid composition analysis suggested that two distinct sub-populations of sauger and white bass exist in the Ohio River that can be separated as a downstream and upstream cohort. Lastly, anglers sought and caught migratory species (i.e. sauger, walleye, paddlefish, and hybrid striped bass) at tailwaters reaches adjacent to locks and dam complexes during peak migratory periods.

Consequently, results from these collaborative studies suggest that:

e. Migratory fish species do congregate seasonally downstream of locks and dam complexes,
f. If river conditions are appropriate, Ohio River fish do move through locks and dam complexes,
g. Distinct sub-populations exist between both downstream and upstream reaches, and
h. Minimal interactions between upper and lower river fish occur.

Factors that may be inhibiting fish movement through locks and dam complexes are both ecological and human associated. Biochemical studies of walleye populations in the Ohio River suggest that a distinct sub-population of these percids exist in upstream reaches (White et al. 2004). Other distinct populations of walleye have been identified from Ohio River tributaries such as the Cumberland River sub-basin Rockcastle River (Billington and Sloss 1998), the New River (Palmer and Hallerman 2000), and possible the Big Sandy River (White per. comm.). White et al. (2004) suggested an origin for the

Ohio River haplotype in the Teays River (Flint 1971). Palmer and Hallerman (2000) also suggested a Teays River origin for walleye from the New River and the Rockcastle River. These results suggest that upper Ohio River fish species may have been historically segregated from downstream populations. Fish species community structure also suggest that differences do exist between upstream and downstream composition (ORSANCO 2002).

Behavioral characteristics of sauger in large river systems are fairly well-known (St. John 1990, TVA 1991, Pitlo 1992, Pegg et al. 1997). In the late fall and early winter, sauger migrate upstream to below high-lift dams and concentrate in these tailwater reaches. Initiation of migration appears to be a factor of water temperature and increased flow. As water temperature rises in the early spring, male sauger move to spawning shoals and may remain for weeks until spawning is complete. In contrast, female sauger may remain on spawning shoals for a period of only days. Once spawning has been completed, both sexes disperse from spawning eras. Several investigators have reported movements in excess of 100 miles.

Movement through locks in an upstream direction has been documented by TVA (1991) and Pegg et al. (1997). TVA (1991) suggested that the locations of the discharge structures associated with locks are important in the upstream passage of sauger. Discharges ports in close proximity to river flow were hypothesized as a positive factor in fish passage. Locks with discharge ports in close proximity to river flow allowed upwards to 25% of sauger to pass during peak peaks. In contrast, no sauger passed at locks with discharge ports at greater distance from river flow. Pegg et al. (1997) reported that 4 of 35 (11%) sauger moved through the Pickwick Locks and Dam

Complex on the Tennessee River while the remaining 31 sauger remained within 31km of the complex until the conclusion of the spawning period. TVA (1991) classified the Pickwick lock as one highly compatible to fish passage.

Retention time in close proximity to a fish barrier has been suggested as an additional factor in promoting fish passage (Barry and Kynard 1986). Large variations for migratory species such as blueback herring (Chapplear and Cooke 1994) and sauger (Pegg et al. 1997) have been reported. Pegg et al. (1997) reported that sauger remain in close proximity to a navigational locks and dam complex for a period of months in contrast to clupeid species which may only remain for a period of days (Bailey et al. (2004). Zigler et al. (2003) reported that paddlefish remained in tailwater areas for considerable time periods during the winter, summer, and fall, but moved downstream during the spring period.

Results from the present study indicated that although sauger and white bass moved primarily upstream through locks and dam complexes, two distinct patterns were evident. At lower river complexes, these species moved soon after tagging with no evidence of river conditions affecting migration. In contrast, inter-pool movement at upper river complexes was linked to high flow river conditions and approaching equilibrium of head differential at each locks and dam complex. Consequently, it appeared that although given the opportunity for a period of several weeks during peak migratory seasons, sauger did not migrate through locks in the upper reaches of the Ohio River. Rather, sauger seemed to migrate upstream through gate openings in the dam.

Sauger, as well as all fish species, were afforded an avenue for moving through a canal around the J.T. Myers Locks and Dam complexes during most periods. Paddlefish

movement in the downstream reaches of the river also was noted. Movement through locks have been reported for paddlefish by Zigler et al. (2003) in the upper Mississippi River, as well as during periods of high flow and equal head differential at locks and dam complexes.

The locks in the upper reaches of the Ohio River are similar to those reported by TVA (1991) as not conducive to fish passage. Discharge ports are at distances from the river flow for all complexes, and especially at those that have hydropower facilities. In addition, most gates are either operated to provide a more even flow throughout the river channel or along the opposite shore from the lock chambers. Consequently, fish are either not positively attracted to the lock chamber or ports. TVA (1991) suggested that most fish enter the lock chambers through the ports. Knights et al. (2002) also suggested that fish passage at upstream high-lift dams is not likely because of non-conducive flow patterns.

Ohio River dams are fairly unique in that under extremely high river stages, an open-river condition exist. Knights et al. (2002) postulated that during these open water conditions fish are afforded the greatest opportunity to pass through Ohio River locks and dam complexes. This was especially evident in more upstream complexes where lock chamber and dam operations did not promote passage except during high flow events. Open-river conditions occurred less than 5% of the years for all complexes upstream of the Racine Locks and Dam Complex. In contrast, this condition was achieved for 50% of the years at the J.T. Myers and Newburgh complex (Knights et al. 2002). Inter-pool movement from this study were greatest at these two complexes. Therefore, it is unlikely that fish pass the upstream complexes readily in a normal or low flow year.

River conditions were dissimilar during the study period as compared to historic records (USGS 2004). River stages were extremely high in upstream reaches resulting in open water conditions for 1-5 day periods on at least several occasions. On two of these occasions, sauger that had been tagged prior to open-river conditions were recovered in greater than expected numbers upstream of the complex following open-river conditions. This result suggest that sauger moved upstream through these complexes during open-river conditions and not during normal conditions when the only avenue would be through lock chambers. These results are in concert with Knights et al. (2002).

Inter-pool fish movement in the Ohio River appears to be of two distinct patterns. Fish downstream of Markland Locks and Dam complex appear to move inter-pool more readily, especially at the most downstream locations. Fish upstream of the Markland Locks and Dam complex appear to have more restrictive inter-pool movement patterns and movement is linked to open-river conditions. Minimal fish passage through the Markland Locks and Dam complex was evident suggesting that this complex may be a hindrance to fish exchange within the Ohio River system. Knights et al. (2002) suggested that the Markland Locks and Dam complex is more like those in upstream reaches. Recreational and commercial paddlefish data also suggest that this species has a tendency to concentrate downstream of this complex (Henley et al. 2002).

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Chapter 2

Ohio River Mainstem System Study (ORMSS)

Fish Tagging and Fatty Acid Composition Tasks

Introduction

Fish passage through large navigational lock and dam complexes has been proposed as problematic within the Ohio River sub-basin (USACOE 2000). These complexes serve an important role in promoting navigation in the sub-basin by maintaining a nine-foot navigational channel throughout the year. In contrast, prior to large-scale river alterations the Ohio River was characterized by large fluctuations in water levels during the wetter seasons and a great reduction in river flow resulting in river channels at times of less than 5 feet during the summer (Cannon and Hoffman 1937). Navigation-based alterations to the Ohio River was initiated in the early 1800s with the clearing of woody debris and the construction of a wing dam at Henderson Bar in 1825. These efforts were continued and by 1929 complete canalization of the Ohio River was accomplished through a series of 52 lock and dam complexes (USACOE 1979). The completion of 20 "high-lift" dams began in the 1930s and will culminate with the construction of the Olmstead Lock and Dam complex. The high lift dams provide greater stability to river hydrologic dynamics.

Fish passage problems related to locks and dam complexes are well documented for salmonid fish species (Bergkamp et al. 2000). In contrast, impacts to warmwater species have not been as well documented, but some evidence does suggest that potential impacts may be problematic. Pearson and Pearson (1989) stated that the elimination of

Alabama shad in the Ohio River sub-basin was partially attributed to impaired movement due to high lift dams. Other reviews of tagging and distributional data suggest that movement of large river species such as paddlefish and shovelnose sturgeon may be reduced leading to a reduction in range expansion (Henley et al. 2002; ORSANCO 2002). This is especially critical with water quality improvements in the middle and upper Ohio River leading to increased habitat for large river fish species.

Impaired fish movement has also been suggested as one factor in the demise of several freshwater mussel species, which require a fish host for reproduction (Neeves 1999). Two species, the ebony shell and elephant ear mussel, have declined partially due to the impairment of skipjack herring movement in the upper Mississippi River (Becker 1983).

The suggestions that fish passage may be impaired in the Ohio River sub-basin was a concern expressed by several federal and state biologists. In response to these concerns, the study reported herein was proposed and funded to provide insight into fish passage of three highly migratory species. Sauger and white bass were selected because of their migratory behavior, potential for serving as freshwater mussel hosts, and their selection by recreational anglers, which promoted the reporting of tagged individuals (Pegg et al. 1997). In addition, walleye were included because of importance in the upper Ohio River fish community, the presence of a unique haplotype in this reach of the river, and their migratory behavior (White et al. 2004). Saugeye were also included because of their migratory behavior.

Paddlefish were selected because of their migratory behavior, importance as a commercial fish, and the potential to collaborate with several long-term studies. It was

believed that these three species represented behavioral patterns of many migratory species inhabiting the Ohio River; consequently, these species would serve as a model for future discussions.

Specific objectives were:

1. To determine short-term movement patterns of target species,
2. To ascertain hydrologic conditions which may promote the passage of the target species, and
3. To determine interpool cohort differences using fatty acid techniques.

Approach

Fish Tagging Activities:

Sauger, saugeye, walleye, and white bass were collected using pulsed DC boat-mounted electrofishing gear during the Fall 2001; Winter, Spring, and Fall 2002; and Winter 2003 by four ORFMT state agencies at nine tailwaters within the Ohio River sub-basin (Table 1). Initially, target species were to be tagged within the Greenup tailwater (Meldahl Pool), but because of Homeland Security concerns tagging activities from this location were discontinued. To replace the Greenup tailwater location, targeted species were tagged at the Racine (R.C. Byrd Pool) and Belleville (Racine Pool) tailwaters in 2002 and 2003. Each individual fish was separately measured and tagged with a color-coded, uniquely numbered T-Bar anchor tag. A mailing address number and a reward announcement was printed on each tag. Prior to release, each individual fish was retained for a minimum of 10-minutes to insure recovery and fish that appeared stressed were not released.

To inform anglers of the study, posters were placed at local boat docks and ramps, as well as area sporting good stores, and several news releases were issued throughout the region. In all media, anglers were encouraged to return tags with information about

capture location, and date of capture. In addition, project funded clerks at selected tailwaters informed anglers about the program and encouraged them to report tagged fish.

Upon tagging completion, crew leaders submitted data forms to the WVDNR-Parkersburg Office for processing. Data were entered and reviewed to insure quality. Data sets were maintained using Microsoft Excel. Information on tag number, tagging location and date, and size at tagging were linked to each individual fish. Anglers reported the capture of tagged fish via mail, telephone, or e-mail. Information on recapture date and location, as well as if the fish was harvested or released were recorded. If anglers did not report all recapture information, a self-addressed stamped postcard was sent requesting information. All anglers reporting the recapture of a tagged fish were sent a hat.

Movement was ascertained for all recaptured fish if information was available. Significant differences in length frequencies (sauger, walleye, and white bass) among fish tagged, recovered, and creeled (collected by project funded creel clerks) were determined based on the Kolmogorov-Smirnov test (Sokal and Rohlf 1995). Movement was determined both by time period (Fall 2001 Tagged Individuals, etc) and by location (i.e. pool tagged). Direction was noted as either upstream, downstream, or no movement (recaptured within the tagging pool), and the number of locks and dam complexes traversed were determined. Because exact locations of recapture frequently were not provided by anglers, extent and direction of movement was determined in this manner.

Water level and discharge information were acquired from USGS database (USGS 2003) and linked to specific time periods. Water levels at specific locks and dam complexes was acquired from the U.S. Army Corps of Engineers District offices and

elevations between upstream and downstream points at locks and dam complexes were ascertained by subtracting the downstream elevation from the upstream elevation.

Tag loss and total tagging-related mortality (tagging and handling) were estimated from (O'Bara et al. 1999) since the author provided training to all tagging crews. Non-reporting was determined by distributing 50 postcards per tailwater as tag surrogates (O'Bara et al. 1999) and rewards were provided for each returned postcard. Previous studies had estimated nonreporting as low as 7% for black crappie (Elder 1990) to 73% for sauger (Maciena et al. 1998). Annual angler exploitation was defined as a percent of tags returned by anglers (non-adjusted) during a 12-month period after tagging, adjusted for percent of released fish, tag loss, tagging-related mortality, and non-reporting (Jagielo 1991). Annual angler catch also was determined and defined as the percent of tags returned corrected for tag loss, tagging-related mortality, and non-reporting by anglers. Confidence limits (95%) were determined using a binomial distribution for annual angler exploitation and catch, and unless otherwise indicated were the measurement of variance. Annual exploitation and catch was determined for sauger, all percids (sauger, saugeye, and walleye), and white bass.

Paddlefish were collected by ORFMT biologists and project staff, as well as commercial fishers. ORFMT biologists used variable size (length x width) gill nets consisting of a single panel of 127mm square-bar mesh, as well as pulsed DC boat-mounted electrofishing gear to collect paddlefish. Sampling was conducted during the fall (2001 and 2002), winter (2002 and 2003), and spring (2002 and 2003). In addition, project staff (observers) traveled with commercial fishers to both recover and tag paddlefish in the Cannelton and McAlpine pools. Upon collection, paddlefish were

checked with the use of a magnetic wand for the presence of a coded-wire tag (CWT), and visually inspected for the presence of a jaw tag or elastomer mark. CWTs had been inserted during a previous MICRA-associated study, jaw tags had been attached to wild paddlefish by ORFMT biologists, and elastomer marks used by WVDNR biologists to identify hatchery-reared fish. Individuals were measured (eye-fork length) and inserted with a metal jaw tags prior to release. Jaw tags were uniquely numbered and information concerning mailing address and rewards were present. Rewards were handled by the Kentucky Department of Fish and Wildlife (KDFWR) because most jaw tags returns were thought to come from commercial fishers. An additional effort to collect paddlefish information was conducted through a creel survey conducted by the KDFWR in the lower open section of the river, as well as in the Tennessee River.

Movement was ascertained for all recaptured fish if information was available. Significant differences in length frequencies between tagged and recovered paddlefish were based on the Kolmogorov-Smirnov test (Sokal and Rohlf 1995). Movement was determined by location (i.e. pool tagged) and direction was noted as either upstream, downstream, or no movement (recaptured within the tagging pool). The number of locks and dam complexes traversed also was determined. The duration a paddlefish was at-large was not considered because of incomplete recapture date data provided by commercial fishers.

Fatty Acid Composition Activities:

A more detailed discussion of activities concerned with fatty acid composition tasks is outlined in Wells (2004). This report was submitted as a separate document, but was funded with project funds.

Three fish species: paddlefish, white bass, and sauger were analyzed for lipid and fatty acid composition in order to study the impact of locks and dams upon the lipid and fatty acid composition of these specimens and interpret variation in these profiles. Tissue samples were taken from fish collected by other project personnel using boat-mounted electrofishing techniques under contract to West Virginia Division of Natural Resources (WVDNR) and shipped to the Tennessee Technological University (TTU) Water Center Laboratories. During the project, 121 fish were collected and analyzed from the following Ohio River pools: Hannibal, Belleville, Greenup, Meldahl, Cannelton, and Smithland.

Data for thirteen fatty acids and for total percent lipids were measured. Lipids were extracted from the white muscle tissue. Fatty acids were analyzed by gas chromatography and flame ionization detection with confirmation by gas chromatography—mass spectrometry. The data were analyzed using Statistical Analysis System (SAS) software.

Results

Fish Tagging Activities:

Percids:

Sauger, saugeye, and walleye were tagged from 1 November 2001 through 28 March 2003 at nine tailwater locations within the Ohio River sub-basin. A total of 5,554 sauger, 53 saugeye, and 432 walleye were tagged during the project period (Table 1). Tag retention was estimated at 90%. Total tagging-related mortality was estimated at 22% with 12 % attributed to tagging and 10% attributed to handling. Non-reporting by individual tailwaters is reported in Table 1 and ranged from 20-48%.

Tags were included in this analysis that were returned through March 2004A total of 559 (10%) sauger, 9 (17%) saugeye, and 52 (12%) walleye were reported recaptured by anglers. In addition, 51 sauger and 3 walleye were recovered during scientific-based surveys. Initially, anglers did not provide sufficient information for 70 recaptures, but with follow-up correspondence sufficient information was provide from 48 of the 70 (68%) resulting in 656 usable tag returns.

Length frequency distributions were significantly different for sauger and walleye between tagged and recovered individuals, as well as recovered and creeled individuals for walleye (Figure 1). No significant differences were found between recovered and creeled sauger. For all species, a greater proportion of larger individuals were angler-caught than were tagged.

Based on tags recovered from the 2001-2002 tagging period, corrected catch for sauger was 21% for the Ohio River and ranged from 9% for the R.C. Byrd tailwater to 44% for the J.T.Myers tailwater (Table 2). Riverwide annual angler exploitation was 15% ranging from 4% for the R.C. Byrd tailwater to 41% for the J.T.Myers tailwater. Variable percent harvested was a major factor in determining annual angling exploitation.

Of the 559 tagged sauger reported by anglers, 538 had sufficient information to ascertain movement patterns. Ninety percent (90%) of the sauger recovered was within the Ohio River proper with the remaining being recovered from Ohio River tributaries, No sauger were reported from outside the Ohio River sub-basin. Riverwide, 53% of the tagged sauger reported by anglers from the Ohio River proper displayed no movement (recovered within the tagged-pool), 1% displayed a downstream movement, and 46% displayed upstream movement. Geographically, The percent of tagged-sauger moving to

another pool was greatest for those fish tagged in the Smithland Pool (through J.T. Myers Locks and Dam complex) and the Greenup Pool (through R.C. Byrd Locks and Dam complex). Longitudally, sauger movement patterns were variable (Table 3). Smithland Pool tagged-sauger displayed the greatest affinity to move with only 13% being recovered within the tagged pool and the remainder moving in an upstream direction. The farthest a Smithland Pool tagged sauger moved was upstream through three locks and dam complexes into the McAlpine Pool. In contrast, sauger tagged in the Racine, Belleville, and Hannibal pools displayed an affinity not to move with greater than 70% displaying no movement patterns. Sauger tagged in other pools displayed intermediate movement patterns (Table 3). Few sauger moved upstream through the Markland, Meldahl or the Greenup locks and dam complexes.

Sauger exhibit a tendency to move into a few larger tributaries including the Wabash, Kentucky, Kanawha, and Allegheny rivers (Table 4). Most sauger captured within a tributary river did display an affinity for an adjacent river either entering the tagged-pool of a tributary entering a pool just upstream of the tagged-pool. An example is a fish tagged in the Greenup Pool displayed movement patterns which were characterized by traveling through the R.C. Byrd Locks and Dam complex and then upstream into the Kanawha River. One Smithland Pool tagged sauger did travel upstream through the J.T. Myers Locks and Dam complex and upstream in the Wabash River system into the East Fork of the White River. Sauger recovered in the Allegheny River and Beaver River systems were tagged in either the Hannibal or Pike Island pools and traveled through the New Cumberland, Montgomery, Dashields, and Emsworth locks and dam complexes prior to entering the Allegheny River system.

Although tagged and recovered to a lesser magnitude than sauger, saugeye and walleye displayed similar patterns. Both of these taxa showed a greater affinity not to move (78% of saugeye and 74% of walleye) and no fish moved to downstream pools.

White Bass:

Five hundred and ninety-five white bass were tagged during the project period (Table 1). Length frequency distributions were significantly different for white bass between tagged and recovered individuals (Figure 2). No significant differences were found between recovered and creeled white bass. A greater proportion of larger individuals were angler-caught than were tagged.

Fifty-two white bass were reported as recaptured by anglers. Sixty-five percent (65%) displayed no interpool movement, 2% moved downstream, and 33% moved upstream (Table 5). As with sauger, the percentage of white bass displaying interpool movement was greatest for fish tagged in the Smithland Pool (through the J.T. Myers Locks and Dam complex) and the Greenup Pool (through the R.C. Byrd Locks and Dam complex). Longitudinally, white bass tagged downstream of and including the Greenup Pool moved at a significantly greater rate (47%) than those tagged in upstream of the R.C. Byrd Locks and Dam Complex (22%). Outside of the Ohio River mainstem, white bass only were recovered from the Green River (1 tagged in the Smithland Pool) and Kanawha River (1 tagged in the Greenup Pool).

Percid and White Bass Movement Patterns in Relation to River Hydrologic Dynamics:

Although timing of fish passage was not a stated objective of this study, the time between tagging and recovery can be informative. Sauger were recovered by anglers over 800-days post tagging (Figure 3) and a greater percentage of fish were recovered from

upstream pools as compared to the tagging pool with increased time at-large. A more detailed evaluation of the relationship of time and hydrologic conditions to fish movement appears to be more informative.

The tendency of fish tagged in downstream pools of the river to move at greater rates than upstream-tagged fish suggest that river conditions differed between these two reaches. Sauger tagged in downstream pools displayed interpool movement within 20 days post tagging. In contrast, sauger in upstream pools displayed interpool movement 60 days post tagging (Figure 4). This suggested that sauger although having the opportunity to move through a lock did not readily use this avenue. The greater tendency for all species tagged in downstream pools to display interpool movement suggests that fish generally were afforded avenues other than lock chambers. These avenues may be related to river flow and stage conditions (i.e. when stage differentials between tailwater and pool elevations are minimal such that fish are able to swim through gate openings). In addition, the J.T. Myers Locks and Dam complex affords another avenue with a canal open for fish movement when river stage is at least attainable throughout the year.

Fish tagged in upstream pools did not display similar have a propensity to move through locks and dam complexes suggesting that minimal stage differentials are attained at less frequent intervals. River stages at locks and dams complexes are partially dictated by river levels, but some operational procedures may contribute to interpool fish movement. An evaluation of the difference between downstream and upstream river stages at the Willow Island Locks and Dam complex provided some insight into the operational opportunities for fish passage. Greater than average precipitation resulting in above average river stages was experienced during the study period. Consequently, on

several occasions, the river stage difference approached equilibrium (Figure 5). During one period (December 2001 through March 2002,) fish were tagged during typical river stages (December 16-20, 2001) and recovered by anglers in the same pool soon afterwards (Figure 5). Fish were not recovered upstream of the Willow Island complex until an atypical event resulted in the river stage approaching equilibrium (Figure 6). In December 2002 through March 2003 similar river conditions were present and similar results were observed to 2002.

The influence of river stage and movement patterns was evident when comparing the percent of hours that a locks and dam complex had water level near equilibrium (<=5 foot differential). All species moved through the R.C. Byrd Lock and Dam complex at a greater rate (63%) as compared to other mid-Ohio River lock and dam complexes (Belleville=22% and Willow Island=30%). River stage equilibrium (<=5 foot differential) was achieved 9.4% of the time at the R.C. Byrd Lock and Dam complex during the study period as compared to 1.4 % for the Belleville Lock and Dam complex and 1.6% for the Willow Island Lock and Dam complex (Figure 7). An equilibrium achievement rate of 2.9% at the Racine Lock and Dam complex would suggest opportunities for fish movement, and this was evident by passage of sauger tagged in the Greenup Pool through the Racine Lock and Dam complex (Table 3).

Paddlefish:

Paddlefish were collected primarily in downstream reaches of the Ohio River because of the greater abundance of the species in this section. ORFMT and project biologists handled 1,579 paddlefish during the 29-month period of the study. Fish were collected primarily by biologists using gill nets (1,352), and to a lesser degree by

commercial fishers (189) and electrofishing (29). Most paddlefish (1,516) were processed and released, but a few were either harvested by commercial fishers (58) or died (5) as the result of handling stress.

Six percent of the paddlefish handled by biologists had been inserted with CWTs, and less than 1% (24 of 6,430) of paddlefish handled by KDFWR creel clerks had CWTs. Jaw tags were recovered from 61 paddlefish (1%) of biologists-collected paddlefish. Project clerks at the J.T. Myers, McAlpine, Markland, and Greenup tailwaters recovered no jaw-tagged paddlefish, although over 300 paddlefish were examined. CWTs are being examined by MICRA staff and results will be available at a later date.

Length (eye-fork) frequency distribution were not significantly different between all paddlefish handled and recovered paddlefish (Figure 8). Paddlefish ranged in size from 200mm to 1050mm. No length information was available for paddlefish recovered by independent commercial fishers.

Jaw tags were inserted into 1,488 paddlefish during the project period (Table 6). Eye-fork length ranged from 350mm to 1000mm (Figure 7). Fifty-eight percent were collected and released from the Smithland-J.T. Myers Locks and Dam complexes with the remaining from nine Ohio River pools and Barkley Reservoir in the adjacent Cumberland River.

Movement patterns of recovered paddlefish were provided for 210 of 227 individuals. Commercial fishers were contacted if information was not provided, but a few declined to provide information. Fifty percent of the paddlefish recovered from the Ohio River proper were recaptured within their tagging pool, 22% moved downstream, and 28% moved upstream (Figure 9). Downstream movement was slightly biased since a

larger proportion of the paddlefish were tagged in the most downstream pools. All paddlefish tagged in the Greenup, Racine, and Belleville pools displayed no interpool movement. Small paddlefish (less than 400mm) also displayed no interpool movement (Table 7). Paddlefish were recovered from the Green (2), Tennessee (1), and Wabash (7) river systems. Each of these major Ohio River tributaries were adjacent to pools in which these paddlefish were tagged.

Eight paddlefish tagged within the Ohio River sub-basin were recovered from outside of the sub-basin. One fish was recovered from the Illinois River, one from the Missouri River, and six from the Mississippi River. These Mississippi River recovered individuals had moved both downstream and upstream of the Ohio-Mississippi confluence.

Fatty Acid Composition Activities:

Percent Lipids:

There was no significant difference (á = 0.05) among the mean percent lipids for sauger among the pools sampled. For white bass, percent lipids for the Meldahl Pool were significantly higher than for the Belleville or Greenup pools, with the data for Hannibal, Cannelton, and Smithland pools occurring intermediately.

Fatty Acid Composition:

The fatty acid composition profiles for 13 fatty acids were compared between species and among locations. The mass balances for weight percent of fatty acids for Belleville data were determined to be unacceptable relative to all other locations.

The data indicated that co-extracted interferences were found in the chemical results for Belleville Pool for both sauger and white bass. In order to overcome this

obstacle to data analysis, and produce data for Belleville Pool that could reasonably be compared to the other locations, the data for 11 selected fatty acids was reprocessed to assess the relative contribution of each identified fatty acid while excluding the interferences.

Using statistical procedures for analysis of variance and principal component analysis, the reprocessed data for fish collected in October was used to demonstrate (a) that fish species were separately identifiable within location using the fatty acid profile and (b) that as a biological marker the fatty acid profile indicated the existence of two distinct sub-populations, roughly separated into the upper and lower Ohio River reaches, for both sauger and white bass. The data are interpreted to result as an effect of dam structure on fish movement during the low flow period indicated by fish collected during October.

Discussion

Movement patterns are genetically and behaviorally programmed in many large river fishes and are linked to environmental conditions. Sauger have been reported to display a seasonally movement patterns linked to spawning and cued by river flow and temperature. Several studies suggest that sauger move to a staging area in proximity of an eventual spawning reach and, when conditions are appropriate move into these reaches. For many small to medium non-navigational rivers, large dams inhibit these movement patterns resulting in either loss of spawning opportunities or use of sub-optimal habitat for spawning. In large navigational rivers, the locks and dam complexes provide at least a minimal avenue for upstream migration through locks, but fish affinity for flowing conditions often reduce these avenues. Ohio River locks and dam complexes are fairly

unique in that "open river" conditions can be attained during slightly above normal flow conditions in downstream pools, and during extreme high flow conditions in more upstream pools. During the study period, these "open river" conditions were observed during appropriate seasons and upstream movement was determined. This suggests that when these conditions exist, fish passage occurs.

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Table 1. Non-reporting bias and number of tagged individuals of sauger, saugeye, walleye and white bass for nine Ohio River pools. November 2001 through March 2003.

			Number of Individuals Tagged			
Tailwater	**Pool**	**Non-Reporting**	**Sauger**	**Saugeye**	**Walleye**	**White Bass**
J.T. Myers	Smithland	32	689	0	2	72
McAlpine	Cannelton	36	512	0	0	44
Markland	McAlpine	48	808	5	25	58
R.C. Byrd	Greenup	20	717	8	67	83
Racine	R.C. Byrd	22	308	1	9	28
Belleville	Racine	22	646	11	72	4
Willow Island	Belleville	22	1247	27	225	86
Pike Island	Hannibal	40	457	1	21	161
New Cumberland	Pike Island	40	170	0	11	59
Ohio River		**36**	**5554**	**53**	**432**	**595**

Table 2. Percent tag return (non-adjusted), annual catch, annual exploitation and percent harvest for sauger from for seven Ohio River pools. November 2001 through May 2002.

Tailwater	**Pool**	**Percent Tag Returned**	**Annual Catch**	**Annual Exploitation**	**Percent Harvest**
J.T. Myers	Smithland	21	44	41	94
McAlpine	Cannelton	7	15	12	82
Markland	McAlpine	11	31	20	66
R.C. Byrd	Greenup	5	9	4	45
Willow Island	Belleville	9	22	13	60
Pike Island	Hannibal	6	14	7	50
New Cumberland	Pike Island	4	10	6	57
Ohio River		10	21	15	69

Table 3. Number and percent of sauger recovered by tagged pool and movement patterns for nine Ohio River pools. November 2001 through March 2004.

Movement Patterns	Ohio River		Tagged Pool							
			Smithland		Cannelton		McAlpine		Greenup	
	No.	%	No.	%	No.	%	No.	%	No.	%
D2	1	0	0	0	0	0	0	0	1	3
D1	5	1	0	0	0	0	0	0	1	3
NM	269	53	13	13	15	68	33	42	19	58
U1	137	27	52	54	3	14	26	33	6	18
U2	60	12	21	22	3	14	15	19	5	15
U3	19	4	10	10	1	5	3	4	1	3
U4	9	2	1	1	0	0	0	0	0	0
U5	5	1	0	0	0	0	2	3	0	0
U6	0	0	0	0	0	0	0	0	0	0
U7	1	0	0	0	0	0	0	0	0	0
Total	**506**	**100**	**97**	**100**	**22**	**100**	**79**	**100**	**33**	**100**
Movement Patterns	**R.C. Byrd**		**Racine**		**Belleville**		**Hannibal**		**Pike Island**	
	No.	%	No.	%	No.	%	No.	%	No.	%
D2	0	0	0	0	0	0	0	0	0	0
D1	0	0	0	0	2	2	1	3	1	9
NM	10	37	61	78	90	70	22	71	6	55
U1	11	41	14	18	21	16	4	13	0	0
U2	3	11	3	4	7	5	1	3	2	18
U3	0	0	0	0	2	2	0	0	2	18
U4	2	7	0	0	3	2	3	10	0	0
U5	1	4	0	0	2	2	0	0	0	0
U6	0	0	0	0	0	0	0	0	0	0
U7	0	0	0	0	1	1	0	0	0	0
Total	**27**	**100**	**78**	**100**	**128**	**100**	**31**	**100**	**11**	**100**

Table 4. Number of sauger recovered in tributaries of the Ohio River and movement patterns for eight Ohio River pools. November 2001 through March 2004.

	Tagged Pool							
	Smithland	Cannelton	McAlpine	Greenup	Racine	Belleville	Hannibal	Pike Island
Allegheny	0	0	0	0	0	0	3	2
Beaver	0	0	0	0	0	0	2	1
Big Sandy	0	0	0	1	0	0	0	0
Hocking	0	0	0	0	1	0	0	0
Kanawha	0	1	2	9	0	0	0	0
Kentucky	0	2	1	0	0	0	0	0
Muskingum	0	0	0	0	3	2	0	0
Wabash	2	0	0	0	0	0	0	0

Table 5. Number and percent of white bass recovered by tagged pool and movement patterns for nine Ohio River pools. November 2001 through March 2004.

	Tagged Pool									
Movement Patterns	All		Smithland		McAlpine		Greenup		R.C. Byrd	
	No.	%	No.	%	No.	%	No.	%	No.	%
D5	1	2	0	0	0	0	0	0	0	0
D4	0	0	0	0	0	0	0	0	0	0
D3	0	0	0	0	0	0	0	0	0	0
D2	0	0	0	0	0	0	0	0	0	0
D1	0	0	0	0	0	0	0	0	0	0
NM	34	65	4	57	4	67	5	38	3	75
U1	10	19	1	14	2	33	4	31	1	25
U2	7	13	1	14	0	0	4	31	0	0
U3	1	2	1	14	0	0	0	0	0	0
Total	**52**	**100**	**7**	**100**	**6**	**100**	**13**	**100**	**4**	**100**
Movement Patterns	**Racine**		**Hannibal**		**Pike Island**		**Belleville**			
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**		
D5	0	0	0	0	0	0	1	20		
D4	0	0	0	0	0	0	0	0		
D3	0	0	0	0	0	0	0	0		
D2	0	0	0	0	0	0	0	0		
D1	0	0	0	0	0	0	0	0		
NM	1	100	12	86	3	100	2	40		
U1	0	0	1	7	0	0	1	20		
U2	0	0	1	7	0	0	1	20		
U3	0	0	0	0	0	0	0	0		
Total	**1**	**100**	**14**	**100**	**3**	**100**	**5**	**100**		

Table 6. Number and percent of paddlefish handled and jaw tagged for eleven Ohio River sub-basin pools. November 2001 through December 2003.

	Handled		Jaw Tagged	
Pool	**No.**	**%**	**No.**	**%**
No. 52	235	15	235	16
Smithland/J.T. Myers	874	55	864	58
Cannelton	11	1	11	1
Newburgh	174	11	115	8
Racine	2	0	1	0
McAlpine	26	2	26	2
Medlahl	38	2	38	3
Markland	94	6	94	6
Greenup	80	5	73	5
Belleville	25	2	11	1
Barkley	20	1	20	1
Ohio River sub-basin	1,579	100	1,488	100

Table 7. Number and percent of paddlefish recovered by tagged pool and movement patterns for nine Ohio River pools. November 2001 through March 2004.

	Tagged Pool							
Movement Pattern	**All**		**Pool 52**		**Smithland/Myers**		**Newburgh**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
D6	1	1	0	0	0	0	0	0
D5	2	1	0	0	0	0	0	0
D4	0	0	0	0	0	0	0	0
D3	4	2	0	0	0	0	0	0
D2	6	3	1	14	3	2	0	0
D1	27	15	0	0	20	17	0	0
NM	90	50	5	71	51	42	5	83
U1	13	7	1	14	10	8	1	17
U2	36	20	0	0	36	30	0	0
U3	1	1	0	0	1	1	0	0
Total	180	100	7	100	121	100	6	100

	Tagged Pool							
Movement Patterns	**McAlpine**		**Meldahl**		**Markland**			
	No.	**%**	**No.**	**%**	**No.**	**%**		
D6	0	0	0	0	1	5		
D5	2	25	0	0	0	0		
D4	0	0	0	0	0	0		
D3	0	0	0	0	4	18		
D2	0	0	0	0	17	77		
D1	1	13	2	100	0	0		
NM	4	50	0	0	0	0		
U1	1	13	0	0	0	0		
U2	0	0	0	0	0	0		
U3	0	0	0	0	0	0		
Total	8	100	2	100	22	100		

	Tagged Pool							
Movement Patterns	**Greenup**		**Racine**		**Belleville**			
	No.	**%**	**No.**	**%**	**No.**	**%**		
D2	0	0	0	0	0	0		
D1	0	0	0	0	0	0		
NM	2	100	1	100	3	100		
U1	0	0	0	0	0	0		
U2	0	0	0	0	0	0		
U3	0	0	0	0	0	0		
U4	0	0	0	0	0	0		
U5	0	0	0	0	0	0		
U6	0	0	0	0	0	0		
U7	0	0	0	0	0	0		
Total	2	100	1	100	3	100		

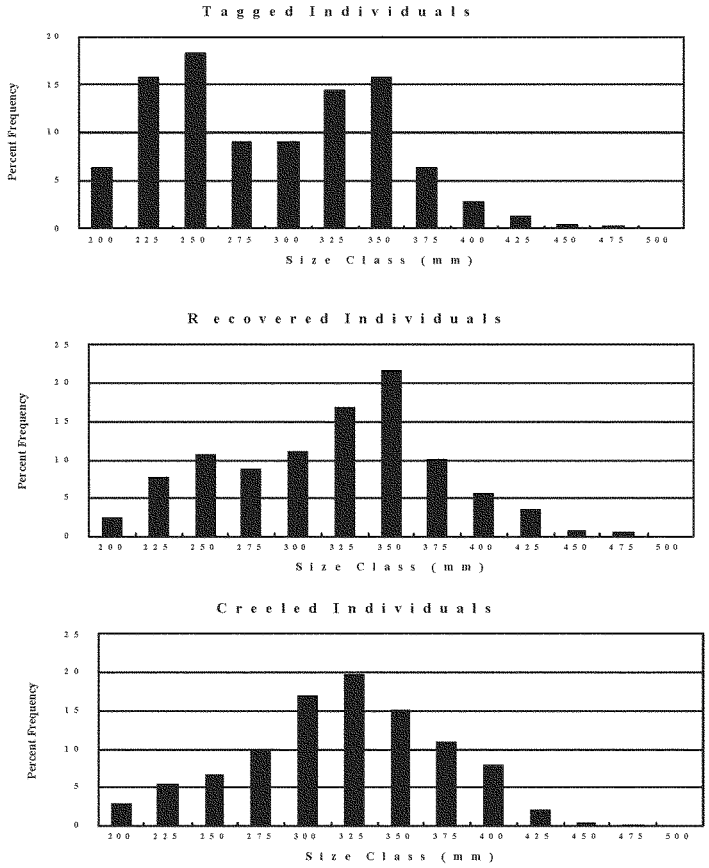


Figure 1. Length frequency histogram for three sub-samples of sauger tagged, recovered, and angler caught from the Ohio River sub-basin. December 2001 through March 2004.

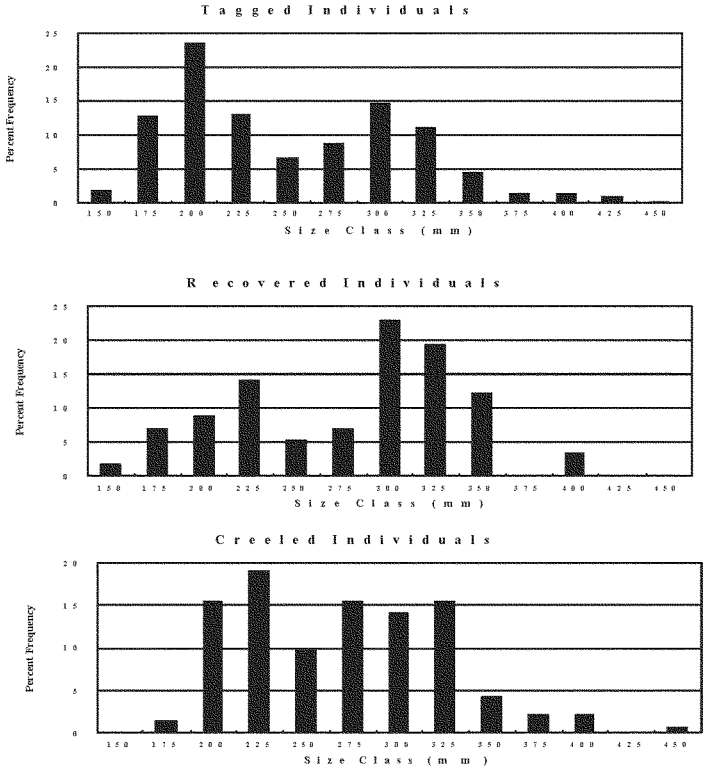


Figure 2. Length frequency histogram for three sub-samples of white bass tagged, recovered, and angler caught from the Ohio River sub-basin. December 2001 through March 2004.

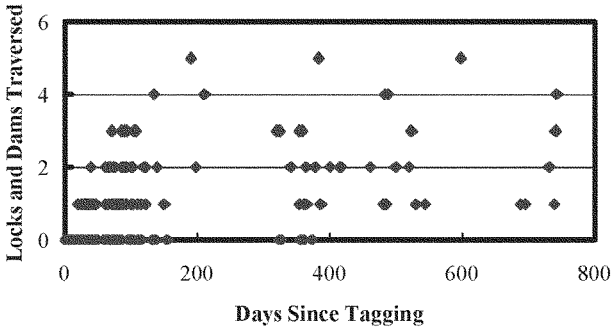
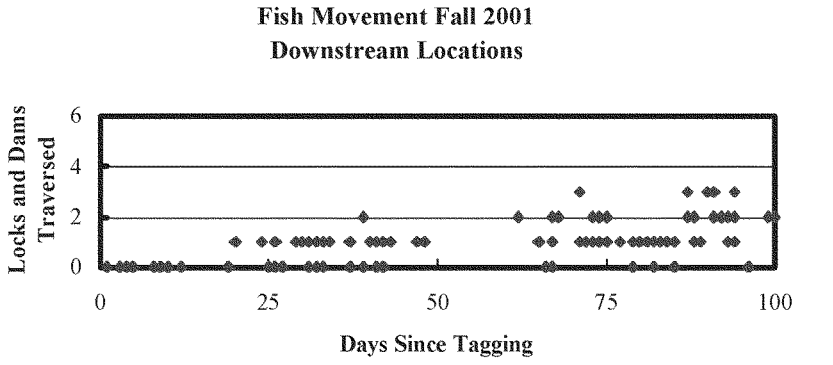


Figure 3. Number of locks and dam complexes traversed and days since tagging for sauger tagged during the Fall 2001 within the Ohio River sub-basin.



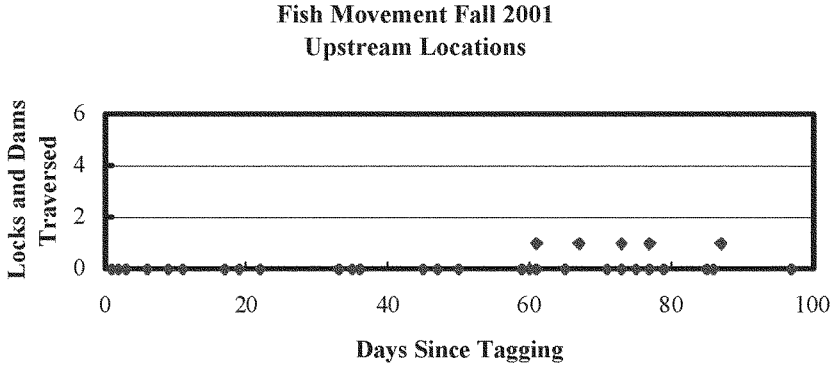


Figure 4. Number of locks and dam complexes traversed and days since tagging for two river locations within the Ohio River sub-basin. December 2001 through March 2002.

Downstream Locations = downstream and including McAlpine pools
Upstream Locations= upstream and including Belleville pools

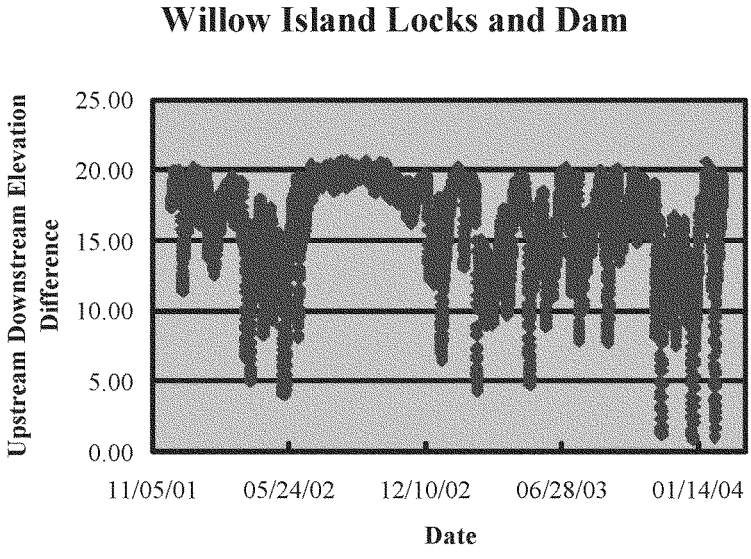


Figure 5. River stage differences (upstream-downstream) for the Willow Island Locks and Dam complex of the Ohio River. November 2001 through January 2004.

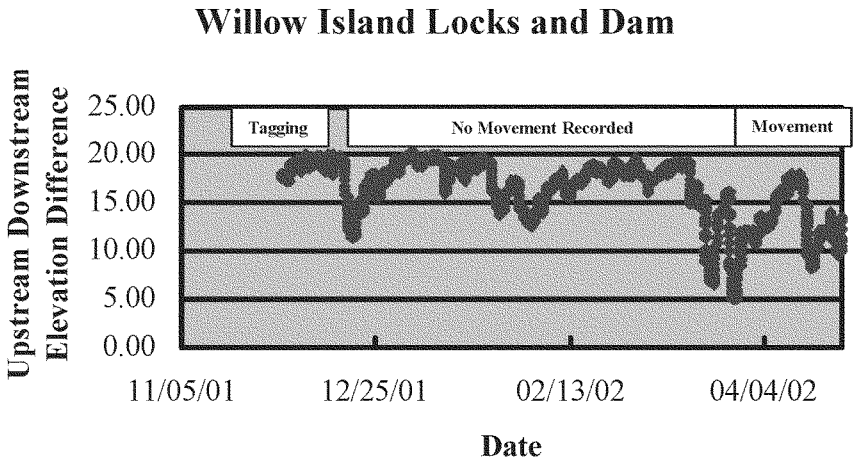


Figure 6. River stage differences (upstream-downstream) for the Willow Island Locks and Dam complex of the Ohio River (November 2001 through April 2002) in relationship to sauger tagging and movement.

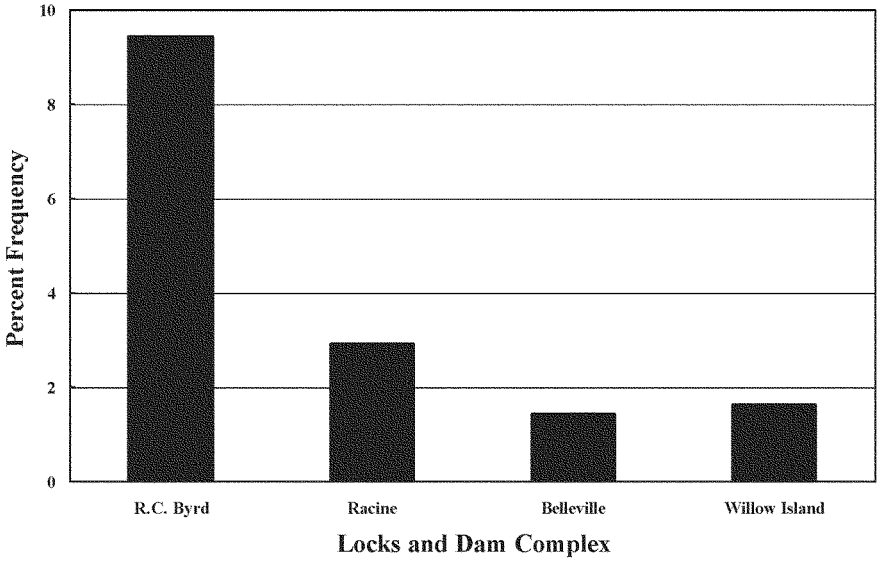


Figure 7. Percent of time by hours that river stage differences (upstream-downstream) is equal to or less than five feet on four middle Ohio Rive locks and dam complexes (November 2001 through January 2004).

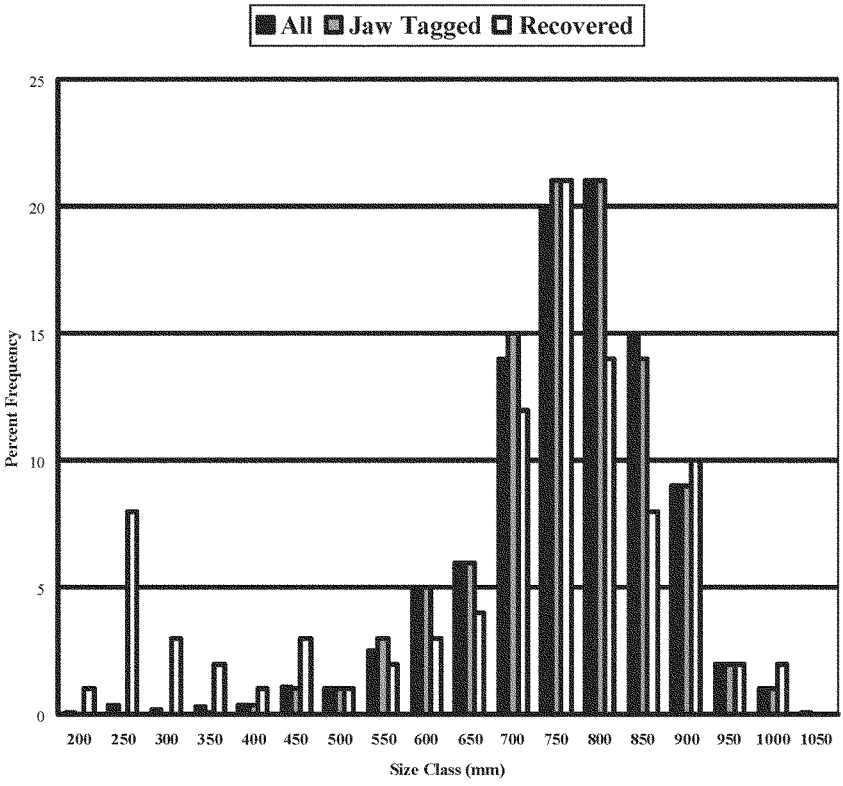


Figure 8. Length frequency histogram for three sub-samples of paddlefish handled, jaw tagged, and recovered from the Ohio River sub-basin. December 2001 through March 2003.

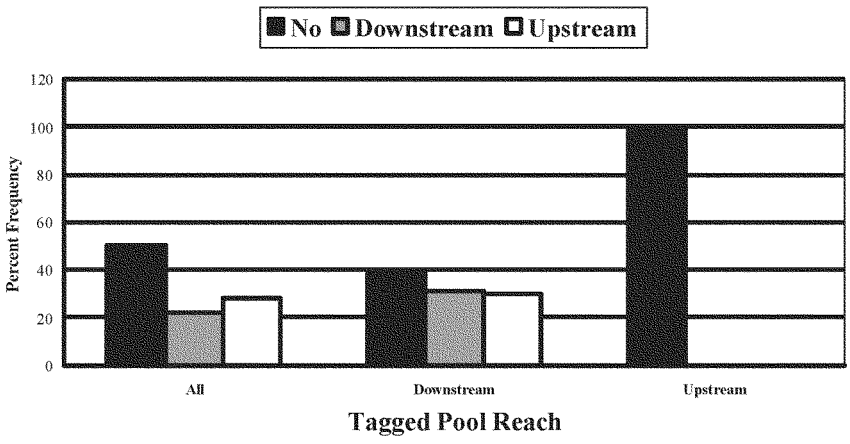


Figure 9. Movement patterns as described by percent frequency for Ohio River paddlefish tagged in three locations. December 2001 through March 2003.

Chapter 3

Ohio River Mainstem System Study (ORMSS)

Fish Passage: Direct Observation Task

Introduction

Fish passage through large navigational locks and dam complexes has been proposed as one factor in the paucity of re-colonization of many large river species within the Ohio River sub-basin (USACOE 2000). Although often common in downstream reaches, large river species have not efficiently re-colonized the upstream Ohio River reaches even with the vast improvement of water quality. This has lead many state and federal agencies to initiate restoration of large river species such as paddlefish and shovelnose sturgeon in the upper Ohio River sub-basin (Henley et al. 2002).

The construction of fifty low-head locks and dam complexes in 1800s and early 1900s initially lead to the temporal fragmentation of the Ohio River. Although, seasonally flooding did offer an opportunity for fish to migrate along the river course, this fragmentation was further enhanced with the completion of 20 high-lift dams maintaining a 2.7m channel (Pearson and Pearson 1989). This disruption of natural hydrologic regimes has resulted in a cascade of declining ecological conditions (Ligon et al. 1995).

Fish passage problems related to locks and dam complexes are well documented for salmonid fish species (Bergkamp et al. 2000). Warmwater species are not as well studies, but several species appear to be impacted. Pearson and Pearson (1989) attributed the elimination of Alabama shad in the Ohio River sub-basin to reduced movement due to

high lift dams. Reviews of tagging and distributional data suggest that decreased interpool movement opportunities of large river species such as paddlefish and shovelnose sturgeon may be a factor in impeding range expansion back to their historic accounts (Henley et al. 2002; ORSANCO 2002). This is especially important relative to improved water quality in the middle and upper Ohio River leading to increased habitat for large river fish species.

The suggestions that fish passage problems exist in the Ohio River sub-basin was expressed by both federal and state biologists. Consequently as part of the Ohio Roiver Mainstem System Study of navigational activities on the Ohio River, the study reported herein was proposed and funded.

Specific objectives were:

4. To determine if fish community structure within lock chambers are similar to tailwater related fish community,
5. To determine short-term movement patterns of target species, and
6. To ascertain hydrologic conditions which may promote the passage of the target species.

Approach

Field investigations were segmented into two phases. First, an investigation was conducted to determine if the fish community inhabiting lock chambers were representative of tailwater reaches. The second phase was to determine short-term movement patterns of targeted species.

The Winfield Locks and Dam complex was selected as the study site. This complex is located on the Kanawha River (KRM 31.1), a major tributary of the Ohio River. The tailwater reach of the Winfield Locks and Dam complex is open to the Ohio River and part of the R.C. Byrd Pool. Consequently, fish fauna are similar to Ohio River

tailwaters. Structural, the locks and dam complex is the newest within the Ohio River sub-basin being completed in 1997. The main lock is 34m feet wide and 244m long. Two smaller (17m x 110m) auxiliary locks are present.

Fish community structure was determined during May, August, and September 2002. Pulsed DC electrofishing equipment, gill nets, and hoop nets were employed to determine the fish composition of the tailwater. The lock chamber was surveyed in September 2002 using standard fish toxicant applications. The auxiliary chamber was used in this task. All fish were identified to species relative abundance determined. Because each technique provided a different catch per unit effort metric, no standard metric was available.

Intensive fish sampling tasks were conducted from 19 May 2003 through 29 July 2003. Specific study locations were the Winfield Locks and Dam complex tailwater (KRM 28.0-30.8), the R.C. Byrd Pool (KRM 19.0-28.0; ORM 240.0-237.5), the Winfield Pool (KRM 31.5-40; KRM 66.0-67.7). These locations were selected because of the proximity to the Winfield Locks and Dam complex (KRM 28.0-30.8, KRM 19.0-28.0, and KRM 31.5-40), as well as locations where fish were know to congregate (KRM 66.0-67.7; ORM 240.0-237.5). The Winfield Locks and Dam complex tailwater was the location of all tagging and marking tasks. Other locations, as well as the Winfield Locks and Dam complex tailwater, were surveyed for the recovery of tagged and/or marked fish.

Six fish species were selected to represent large river fishes occupying different behavior and habitat guilds. All species are common to the Ohio River sub-basin. Hybrid striped bass were selected because of their migratory tendencies. Results from an ongoing

study suggest that hybrid striped bass within the Ohio River move great distances (WVDNR 2004). Sauger and skipjack herring also were selected because of their migratory tendencies. Sauger represent a benthic species and skipjack herring a pelagic species. Channel catfish movement trends are not well-known, but are considered habitat generalists and are common in large rivers. Smallmouth buffalo and freshwater drum are both abundant in large river habitats, and are especially common in tailwater reaches associated with locks and dam complexes.

Hybrid striped bass were collected using pulsed DC boat-mounted electrofishing gear during six periods in May and June 2003 (Table 1). Each individual were separately measured and tagged with color-coded, uniquely numbered T-Bar anchor tags. A mailing address number and a reward announcement was printed on each tag. Prior to release, individual fish were retained for a minimum of 10-minutes to insure recovery and fish that appeared stressed were not released.

The remaining species also were collected using pulsed DC boat-mounted electrofishing gear during six periods in May and June 2003 (Table 1). Fish were held in well aerated live-wells prior to marking with elastomer injections. Fish were injected with three colors (yellow, red, and green) marks in either a caudal, pelvic, or pectoral fin. The combination of color and mark location enabled investigators to identify individuals as to the tagging day.

Upon the completion of tagging and/or marking, all fish were released within 0.4km of the end of the lock wall. Fish were observed to insure that equilibrium was achieved and that fish exhibited a positive response to water flow.

Recovery tasks included electrofishing surveys at the previously described

locations using pulsed DC boat-mounted electrofishing gear. At each location, investigators expended a minimum of 3-hours of peddle-time and attempted to collect as many of the target species as possible. Target species were netted and examined to determine the presence or absence of tags and/or marks. To expedite sampling and an attempt to increase sample size, no individual measurements were taken of target species during the recovery phase.

Anglers were encouraged to return tags from recaptured hybrid striped bass through both active and passive methods. Investigators questioned anglers at the Winfield, Racine, and Marmet tailwaters during the May-July period when surveys were conducted. In addition, posters were placed at local boat docks and ramps, and a news release was provided to local newspapers. Anglers were encouraged to return tags and provide information of location and date of recapture.

Water level and discharge information were acquired from USGS database (USGS 2003) and linked to specific time periods. Water levels at specific locks and dam complexes was acquired from the U.S. Army Corps of Engineers District offices and elevations between upstream and downstream points at locks and dam complexes were ascertained by subtracting the downstream elevation from the upstream elevation.

Movement was ascertained for all recaptured fish (tagged and marked) by both electrofishing and angling techniques. Movement was determined both longitudinal and temporal.

Results

Fish Composition:

Fish species composition was determined from the tailwater reach and the lock chamber to determine if communities were similar. Species common to both habitats were gizzard shad, the minnows and shiners (ghost shiner, emerald shiner, and channel shiner), and freshwater drum (Table 2). Species more common in tailwater habitats were white bass, skipjack herring, and sauger, and in lock chamber habitats were channel catfish, the sunfishes (*Lepomis* and *Pomoxis*), as well as hybrid striped bass. Species such as some of the catostomids and centrarchids were fairly uncommon in both types of habitats. More migratory species appeared to occupy both habitat types, but to a differing abundance. Abundant migratory species in the lock chamber habitat included hybrid striped bass and gizzard shad. White bass, sauger, and gizzard shad, all migratory species, were more common in the tailwater sections. Common more lenthic species, such as the centrarchids, were more common in the lock chamber habitats.

Short-term Movement Studies:

The selection of hybrid striped bass, sauger, smallmouth buffalo, skipjack, freshwater drum, and channel catfish as study species was partially based on findings reported in the previous section. These species were found to be both abundant and at least temporarily inhabiting a lock chamber.

Hybrid Striped Bass Movement Patterns: Hybrid striped bass were tagged with T-bar anchor tags on six occasions within 15-days. One-hundred and thirty-eight individuals were tagged ranging in size from 280-630mm in total length (Table 3). The majority of the fish were tagged and released on 20 May, 22 May, 27 May, and 28 May. Investigators recovered 4 (3%) tagged individuals within the first 15 days following tagging (Table 4). No fish were recovered using electrofishing techniques after 4 June, nor were any fish

recovered from outside of the Winfield Tailwater. Hybrid striped bass tagged on 22 May were recovered on 27 May and 2 June approximately 0.5km downstream of the Winfield Locks and Dam complexes. One hybrid striped bass tagged on 27 May was recovered on the dam side of the complex (w/in 0.25km of dam near the hydropower discharge) on June 2. A second hybrid striped bass tagged on 28 May and recovered on 2 June was located approximately 0.5km downstream of main lock chamber. Although hybrid striped bass were released in the area just downstream of the main and auxiliary lock, in the main lock, as well as the downstream of the miter gates, no fish were collected in these areas.

Anglers caught 15 (11%) of the tagged hybrid striped bass. Twelve recaptured hybrid striped bass were caught from either the R.C. Byrd Pool (Winfield Tailwater, Kanawha River, or the Racine Tailwater, two from the Racine Pool (Belleville Tailwater), and no recapture location was reported for one individual (Table 5). No hybrid striped bass displayed an upstream movement pattern through the Winfield Locks and Dam complex.

Most re-captured hybrid striped bas were angler-caught from the Winfield Tailwater (9 individuals) indicating little movement. Anglers caught tagged-individuals up to 76 days following tagging within the Winfield Tailwater. Two 20 May tagged-fish were reported captured within 5 days of tagging. Both individuals were caught in the Winfield Tailwater adjacent to the hydropower unit discharge. All other individuals were caught by anglers at least 15-days following tagging (Table 5).

Intra-pool movement patterns were noted for two individuals. One 20 May tagged-individual was recaptured 86 days later just downstream of the Racine Locks and

Dam Complex. An additional 22 May tagged-individual was caught at the confluence of the Ohio and Kanawha rivers following a 97-day period (Table 5).

Two tagged hybrid striped bass did display inter-pool movement patterns. Both individuals moved in a downstream pattern and through the Racine Locks and Dam Complex (Ohio River) prior to capture just downstream of the Belleville Locks and Dam Complex. These fish were at-large for a 31 and 43 day period (Table 5).

Two 20 May tagged-fish were reported captured within 5 days of tagging. Both individuals were caught in the Winfield Tailwater adjacent to the hydropower unit discharge. All other individuals were caught by anglers at least 15-days following tagging (Table 5).

Multi-species Short-term Movement Patterns: Sauger, channel catfish, smallmouth buffalo, and freshwater drum were selected based on behavioral characteristics and their abundance in the Ohio River sub-basin. Fish were inserted with either yellow, red, or green elastomer in either the caudal, pelvic, or pectoral fins (Table 3). Seventy-nine sauger, 81 smallmouth buffalo, 120 skipjack herring, 150 freshwater drum, and 120 channel catfish were inserted in May-June 2003. Recovery tasks were conducted for a period through 29 July 2003. No marked skipjack herring were recovered during the study period. Skipjack herring, although an excellent candidate species for a movement study, are difficult to maintain and easily stressed. Marked individuals of all other species were recovered during the study period.

Twelve sauger (15%) were recovered from the Winfield Tailwater within 10 days of marking. No sauger were recovered after 2 June or from locations outside of the Winfield Tailwater. Similarly, channel catfish (15 of 120-12%), smallmouth buffalo (3

of 81-4%), and freshwater drum (9 of 150-6%) were recovered only from the Winfield Tailwater within 10 days of marking (Table 6).

Discussion

The fish fauna inhabiting the lock chamber of large navigational facilities were often used to assess the biotic health of large rivers (Lowman 2000) and were historically considered representative of these unique river systems. A review of ORSANCO (2002) indicated that fewer larger river fishes (paddlefish etc) were collected in tradional lock chamber surveys. Species composition structure information collected in this study further suggests that lock chambers represent a fairly unique assemblage of fish species and may not be truly representative of the fish fauna found in tailwater reaches. This further suggests that many migratory species are not attracted to lock chamber and consequently are not afforded the opportunity to pass through these complexes when typical navigational lockage operations are preformed.

Short-term movement patterns reported in this study suggest that several factors may be important in providing opportunities to fish passage. Several investigators have suggested that river stage (primarily increasing) may influence fish movement behavior leading to an increased passage through locks and dam complexes. Fish were tagged during both an increasing and decreasing river stage in this study (Figure 1), but no movement was detected. Interestingly, upstream movement through locks and dam complexes were noted during an accompanying study of sauger and white bass. This movement appeared to be triggered by increasing water levels and the approachment of open river conditions. Although water levels were increasing and at above normal levels,

the condition at the Winfield Locks and Dam Complex did not reach open river condition until after 18 June.

A secondary factor that may explain the paucity of upstream movement and passage through the Winfield Locks and Dam Complex may be the geographical location of the complex. Several investigators have suggested that fish inhabiting a tributary river may show a greater affinity to the larger parental river. All fish recovered from this study that displayed movement were located downstream of the complex and several were in the Ohio River. This affinity for larger river by great river species, especially during abnormal high flows may be a behavioral trait that hinders the re-colonization of great river species in large tributary rivers. A review of ORSANCO (2002) and WVDNR (fish database) suggests that this may be occurring.

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Table 1. Survey scheme for tasks conducted at the Winfield Locks and Dam Complex, May through July 2003.

	May 2003									
Location	19-May	20-May	21-May	22-May	23-May	27-May	28-May	29-May	30-May	
Winfield TW										
Winfield Pool										
Racine TW										
R.C. Byrd Pool										
	June 2003									
Location	2-Jun	3-Jun	4-Jun	5-Jun	6-Jun	9-Jun	10-Jun	11-Jun	12-Jun	13-Jun
Winfield TW										
Winfield Pool										
Racine TW										
R.C. Byrd Pool										
	June/July 2003									
Location	17-Jun	18-Jun	23-Jun	24-Jun	30-Jun	8-Jul	9-Jul	14-Jul	15-Jul	29-Jul
Winfield TW										
Winfield Pool										
Racine TW										
R.C. Byrd Pool										
		Elastomer Marks								
		T-Bar Tags and Elastomer Marks								
		T-Bar Tags								
		Recovery of Tags and Marks								

Table 2. Species composition and abundance ranks for fish collected from the tailwater and lock chamber at the Winfield Locks and Dam Complex.

		Tailwater Reach		Lock Chamber
Species	**Family**	**Electrofishing Rank**	**Gill Net Rank**	**Toxicant Application Rank**
Gizzard Shad	Clupeidae	1	1	4
Skipjack Herring	Clupeidae	2	2	7
Shorthead Redhorse	Catostomidae	3	6	NA
White Bass	Moronidae	4	3	9
Emerald Shiner	Cyprinidae	5	NA	1
Freshwater Drum	Sciaenidae	6	4	5
Ghost Shiner	Cyprinidae	7	NA	3
Channel Shiner	Cyprinidae	8	NA	2
Smallmouth Buffalo	Catostomidae	9	7	11
Bluegill	Centrarchidae	10	NA	10
Longnose Gar	Lepisosteidae	11	5	8
Common Carp	Cyprinidae	12	8	14
Channel Catfish	Ictaluridae	13	9	6
Flathead Catfish	Ictaluridae	14	11	15
Sauger	Percidae	15	10	20
Largemouth Bass	Centrarchidae	16	NA	16
Hybrid Striped Bass	Moronidae	18	12	12
Longear Sunfish	Centrarchidae	19	NA	18
Spotted Bass	Centrarchidae	22	NA	17
White Crappie	Centrarchidae	27	NA	13
Green Sunfish	Centrarchidae	NA	NA	19

Table 3. Survey days, number of individuals tagged and/or marked and color and location scheme employed at the Winfield Locks and Dam Complex. May through June 2003.

	Date Tagged or Marked								
	19-May	20-May	21-May	22-May	27-May	28-May	2-Jun	4-Jun	Total
	T-Bar Anchor Tags								
Hybrid Striped Bass		34		46	26	24	3	5	138
	Elastomer Marks								
Sauger	12	15	16	22	9	0	5	0	79
Smallmouth Buffalo	10	10	15	17	10	0	19	0	81
Skipjack Herring	20	20	20	20	20	0	20	0	120
Freshwater Drum	25	25	25	25	25	0	25	0	150
Channel Catfish	20	20	20	20	20	0	20	0	120
Color	Yellow	Yellow	Yellow	Red	Red		Green		
Location	Caudal	Pelvic	Pectoral	Caudal	Pelvic		Pelvic		

Table 4. Recovery patterns of t-bar anchor tagged hybrid striped bass form the Winfield Locks and Dam Complex, May-June 2003.

	Date Recovered							
Date Tagged	**20-May**	**21-May**	**22-May**	**27-May**	**28-May**	**2-Jun**	**4-Jun**	**Total**
	Electrofishing Technique Recovery							
20-May		0	0	0	0	0	0	0
22-May				1	0	1	0	2
27-May				0	0	1	0	1
28-May					0	1	0	1
2-Jun							0	0
4-Jun								0
	Angling Recovery							
20-May		1	0	1	0	0	0	2
22-May			0	0	0	0	0	0
27-May				0	0	0	0	0
28-May					0	0	0	0
2-Jun					0	0	0	0
4-Jun							0	0

Table 5. Recovery patterns of angling recaptured t-bar anchor tagged hybrid striped bass from the Winfield Locks and Dam Complex.2003.

Date Tagged	Date Recovered	Days At-Large	Recaptured Location
20-May	21-May	1	Winfield TW
20-May	25-May	5	Winfield TW
20-May	14-Aug	86	Racine TW
22-May	22-Jun	31	Belleville TW
22-May	4-Jul	43	Belleville TW
22-May	28-Jul	67	Winfield TW
22-May	1-Aug	71	Winfield TW
22-May	17-Aug	89	Belleville TW
22-May	27-Aug	97	Kanawha River (KRM 2.0)
27-May	11-Aug	76	Winfield TW
27-May	11-Aug	76	Winfield TW
28-May	15-Jun	18	Winfield TW
28-May	1-Aug	65	Winfield TW
2-Jun	UK	UK	UK
4-Jun	29-Jul	55	Winfield TW

Table 6. Recovery patterns of boat-mounted electrofished recaptured elastomer marked sauger, channel catfish, smallmouth buffalo, and freshwater drum from the Winfield Locks and Dam Complex.2003.

Date Marked										
	Sauger					Channel Catfish				
Recovery	19-May	20-May	21-May	27-May	2-Jun	19-May	20-May	21-May	27-May	2-Jun
20-May	2					0				
21-May	0	3				0	1			
23-May	0	1	2			2	0	3		
27-May	1	0	1			0	0	1		
28-May	0	0	0	0		0	0	0	3	
30-May	0	0	0	0		0	0	0	2	
2-Jun	0	0	0	0		0	0	0	0	
4-Jun	0	0	0	0	1	0	0	0	0	0
9-Jun	0	0	1	0	0	0	0	0	0	0
10-Jun	0	0	0	0	0	0	0	0	1	2
12-Jun	0	0	0	0	0	0	0	0	0	0
13-Jun	0	0	0	0	0	0	0	0	0	0
Total	3	4	4	0	1	2	1	4	6	2
Percent	25	27	25	0	20	10	5	20	30	10

Date Marked										
	Smallmouth Buffalo					Freshwater Drum				
Recovery	19-May	20-May	21-May	27-May	2-Jun	19-May	20-May	21-May	27-May	2-Jun
20-May	0									
21-May	1					2	0			
23-May	0	0	0			0	0	0		
27-May	0	0	0			0	0	2		
28-May	0	0	0	1		0	0	0	0	0
30-May	1	0	0	0		0	0	0	3	0
2-Jun	0	0	0	0		0	0	0	1	0
4-Jun	0	0	0	0	0	0	0	1	0	0
9-Jun	0	0	0	0	0	0	0	0	0	0
10-Jun	0	0	0	0	0	0	0	0	0	0
12-Jun	0	0	0	0	0	0	0	0	0	0
13-Jun	0	0	0	0	0	0	0	0	0	0
Total	2	0	0	1	0	2	0	3	4	0
Percent	20	0	0	10	0	8	0	12	16	0

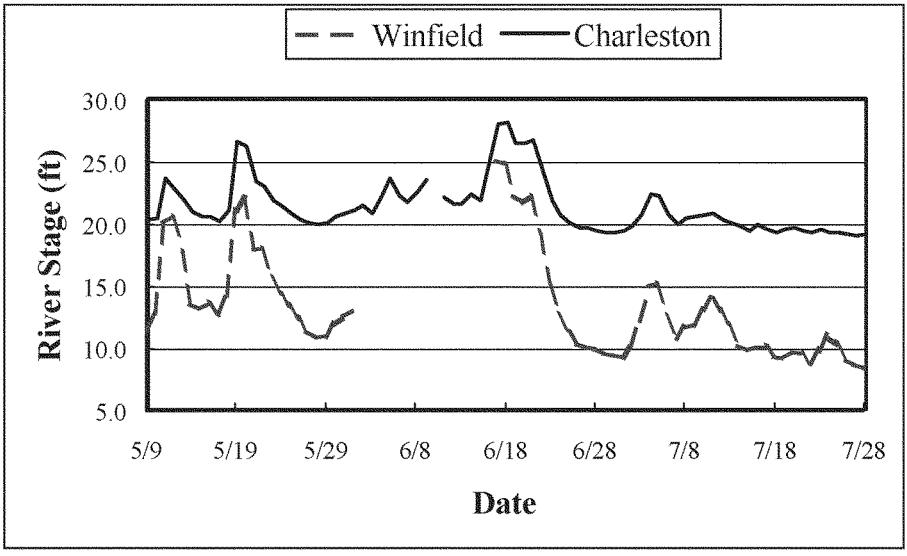

Figure 1. River stages from two gage locations on the Kanawha River for the period May 1 through July 31, 2003.

Chapter 4

Ohio River Mainstem System Study (ORMSS)

Recreational Fishery Survey Task

Introduction

Recreational angling activities provide enjoyment and potential food for many anglers, as well as an economic benefit to local businesses and communities. In 2001, over 34.1 million Americans fished spending 557 million days pursuing both freshwater and saltwater fishes. Americans spent over 35 billion dollars during this period of which over 14 billion were spent directly on angling trips. Anglers seeking freshwater fishes represented 83% of the American fishing public with over 90% of these anglers fishing in systems other than the Great Lakes (USFWS 2003a).

Over 5.5 million anglers within the six Ohio River bordering states fished in 2001 spending over $ 15.00 per trip (USFWS 2003b). In West Virginia, greater than 35% of the population over 16 years of age fished during 2001. Anglers fishing in non-Great Lakes waters spent over 30% of their angling-time fishing in rivers. In West Virginia, anglers spent over 70% of their angling-time fishing in rivers (USFWS 2002b). Consequently, angling is an important recreational activity to many living within the states bordering the Ohio River. In addition, economic benefits to local businesses are vital to their continued financial well-being.

Ohio River angling opportunities are diverse both in species sought and habitat available. Major recreational fisheries exist for sauger, walleye, white bass, hybrid striped bass, as well as the catfishes and black basses. Open river sections, embayments and

backwaters, as well as tailwaters provide habitat for both anglers and fishes. Schell et al. (1996) reported that tailwaters comprise only 1% of available angling habitat in the Ohio River, but generated more than 66% of the total catch. Sauger, catfish, and *Morone* species were reported highly sought in this 1991 survey. Angler expenditures were estimated at 23.7 million dollars in 1992 and 10.2 million dollars for selected Ohio River pools. Tailwaters associated angler expenditures represented nearly 58% of the total expenditures for these two years (Schell et. al 1996).

Tailwater areas are high-use reaches for the Ohio River fisheries. Access to tailwaters by shore anglers is generally excellent providing opportunities to both young and more mature anglers. The maintenance of multi-purpose recreational sites at a few locks and dam complexes by the U.S. Army Corps of Engineers provide one avenue of angler access. Other less developed access sites are designed primarily for the angling and wildlife viewing public. Boat anglers access is more limited with few ramps within close proximity to tailwaters (ORFMT 1995). Safety and land ownership issues often hinder the development of boat access sites, as well as use of tailwater reaches by boating anglers.

Contaminant issues are persistent in the Ohio River in spite of the remarkable clean-up of water quality problems. One legacy of our non-regulated industrial heritage is the continued elevated levels of contaminants in many freshwater fishes. The issuing of consumption advisories on many Ohio River fishes by state health agencies is one aspect of protecting public health. Recently, risk assessment procedures have outlined both the potential risk and benefit of eating fish.

The presence of locks and dam complexes for navigation purposes on the Ohio River and the resulting angling high-use tailwater reaches created by these complexes were paramount in the decision-making process to assess recreational angling activities. In addition, the presence of data collection biologists at tailwater areas during peak sauger and white bass fishing periods would enhance the recapture of tagged individuals in coordination with a related study.

Specific objectives were:

7. To determine recreational angling effort at several Ohio River tailwaters,
8. To ascertain catch and harvest parameters of selected sport fishes,
9. To provide some demographic trend information, and
10. To compare current recreational angling activities with results from previous surveys.

Approach

Angler recreational surveys were conducted at eight tailwaters for a minimum of 12 months (Figure 1). Data collection biologists conducted surveys three days per week (1 weekend period and 2 weekday periods) for an eight-hour period. Survey dates were randomly selected on a seasonal frame. Start times were assigned as either dawn or ½ of the daylight period following dawn on a seasonal frame. Daily survey periods did not overlap. Count times were randomly assigned at four 15-minute intervals per day. These data were used to estimate total angling effort in hours.

A modified bus-stop method was employed at most tailwaters were more than one access site was present (Jones and Robson 1991). Surveys were conducted either on foot at access sites or via boat where access was limited. Boat surveys were conducted primarily at the J.T. Myers and New Cumberland tailwaters.

The ORFMT state agencies developed survey forms that were consistent with past investigations (Schell et al. 1996; Pierce et al. 1983). Information on species caught and

released, directed effort (what species group an individual angler-trip was seeking), length of harvested individuals, and some demographic information were included for query. Prior to the survey, data collection biologists were instructed as to the protocol, as well as provided on-site training by ORFMT state biologists. Most data collection biologists had multi-years of experience and those who did not have extensive experience were initially checked on-site weekly. ORFMT biologists also randomly visited tailwater locations to insure compliance with schedules and protocols. All interviews were conducted by angler groups.

Data were recorded on paper copy and checked monthly by an experienced data collection biologist. Once approved, data were entered using an entry template developed by the Ohio Division of Wildlife. Data sets were visually reviewed, as well as scanned by a program to insure quality. Once, deemed of approved quality, the Ohio Division of Wildlife Inland Fisheries Research Group conducted analysis using a SAS-based analytical package with the methods described in Pollock et el. (1994). Results were reported as catch rate (no./hr), effort (hours), and directed effort (%), and length of harvested individuals (mm; total length except for paddlefish which was recorded as eye-fork length).

Results obtained in the survey described herein were compared with results reported by Schell et al. (1996) and ORFMT (2001). Comparisons were limited because of differences in survey periods, locations, and protocol. A previous study (Pierce et al. 1983) did not provide appropriate comparative data.

Results

Tailwaters were surveyed from September 2001 through February 2003. Most surveys were initiated in either September or October 2001. The Markland tailwater

survey was initiated in February 2002 because of personnel hiring problems. All surveys were concluded by October 2002 except for the Markland, McAlpine, and J.T. Myers tailwaters. These surveys were extended until February 2003 primarily to collect more information for paddlefish tag recovery tasks or to fulfill contractual commitments.

Interviews were conducted on over 8,500 angler-trips at the eight tailwaters. Directed effort groups were dominated by any species (33%) and percids (24%) river-wide. Catfish (17%), *Morone* species (16%), paddlefish (10%), and black bass (1%) were represented. Directed effort groups did differ among tailwaters. The any species group and percid group (Table 1; Figure 2) dominated most upper tailwaters (i.e. including and upstream of the R.C. Byrd tailwater). Catfish were of greater importance in lower river tailwaters. Fifty-seven percent of total angling effort at the J.T. Myers tailwater was directed towards catfish. Paddlefish were of importance at the Markland tailwater with 43% of the effort being expended on this group (Table 1). The Greenup tailwater fishery was dominated by *Morone*-seeking anglers (44%).

Angling effort (hours) was determined monthly by tailwater. Angling effort peaked in the June-August period and in the late-fall for all tailwaters (Table 2; Figure 3). These peaks most likely were related to the catfish fishery (summer), as well as the percid and *Morone* fishery (late-fall). Because not all tailwaters were surveyed during the same 12-month period, comparisons by tailwaters were made only for the February 2002 through September 2002 period (Figure 4). The McAlpine and Willow Island tailwaters had the greatest total angling effort during this period with hours of 19,969 and 15,917 respectively. Also, during this period total angling hours exceeded 10,000 for the Greenup tailwater (12,918 hrs), the J.T. Myers tailwater (12,533 hrs), and the R.C. Byrd

tailwater (10,631 hrs). The Pike Island tailwater (9,475 hrs) and the New Cumberland tailwater (4.924 hrs) experienced the least angling effort during this period (Figure 4).

Catch rates by directed species group are reported herein for sauger, all percids (sauger, saugeye, walleye), hybrid striped bass, white bass, and channel catfish (Table 3). Other species catch rates are available in the accompanying data files. Sauger catch rates ranged from 1.86/hr for the Pike Island tailwater to 0.22/hr for the Markland tailwater (Figure 5). Total percid catch rates ranged from 1.89/hr for the Pike Island tailwater to 0.22/hr for the Markland tailwater (Figure 5). In the Markland, McAlpine, and J.T. Myers tailwaters, the percid fishery was dominated (>98%) by sauger. In other tailwaters, percid directed anglers also caught saugeye and walleye.

Hybrid striped bass catch rates were greatest at the Greenup tailwater (1.64/hr) and least at the R.C. Byrd tailwater (0.19/hr). White bass catch rates were dissimilar with catch rates exceeding 0.75/hr at the Pike Island tailwater (1.28/hr), R.C. Byrd tailwater (0.88/hr), and Willow Island tailwater (0.79/hr). Several tailwaters experienced intermediate catch rates for both hybrid striped bass and white bass (Figure 5).

Channel catfish catch rates were greatest at the J.T. Myers tailwater (0.68/hr) and lowest at the Willow Island tailwater (0.04/hr). Catch rates at the R.C. Byrd and Greenup tailwaters exceeded 0.40/hr (Figure 5).

Paddlefish were only caught at the J.T. Myers and Markland tailwaters in adequate numbers to determine catch rates. Paddlefish catch rate at the Markland tailwater was 0.20 and 0.19/hr. at the J.T. Myers tailwater. An estimated 2,064 paddlefish were caught at all Ohio River tailwaters of which 92% were harvested. The majority of

paddlefish were caught at the Markland tailwater (867-99% harvested) and J.T. Myers tailwater (967-99% harvested).

Estimated number caught of major species at each tailwater for the entire period is presented in Table 4. Over the study period, sauger, hybrid striped bass, and white bass were the dominant species caught. Percent harvested ranged from 92% for paddlefish to 3% for hybrid striped bass. River-wide 34% of sauger, 13% of white bass, 31% of channel catfish and 77% of blue catfish were harvested (Table 4). Percent harvested of major sportfish was influenced by geographic location. Anglers at the J.T. Myers tailwater harvested over 50% of all major sportfish caught. In contrast, anglers at the Willow Island tailwater harvested less than 10% of all sportfish caught (Figure 6).

Anglers harvested sportfish at sizes that suggest some selection (Figure 7). Sauger were harvested at sizes ranging from 150-650mm with the majority in the 300-350mm size classes. Walleye were harvested ranging from 275-625mm with the majority within the 350-475mm size classes. White bass were harvested from a range from 175-450mm with the majority in the 225-325mm size class. Hybrid striped bass were harvested in a range from 275-775mm with the majority in the 400-500mm size class. Striped bass were harvested at a slightly larger size class than hybrid striped bass (Figure 7).

Catfish species length at harvest showed similar results (Figure 8). Blue catfish were caught at a wide range of lengths with only a slight peak in the 350-400mm length range. In contrast, channel catfish length frequency distribution was narrower with the majority in the 400-600mm size classes. Flathead catfish displayed a more skewed length frequency distribution towards larger individual. Eye-fork length of harvested paddlefish

was dominated by individuals in the 700-900mm size classes, but individuals were harvested as small as 300mm (Figure 8).

Anglers resided primarily within the bordering states adjacent to the tailwaters (Table 5). J.T. Myers tailwater anglers were primarily from Kentucky and Illinois. Kentucky is a bordering state, while Illinois anglers have easy boat access. The Willow Island tailwater anglers were primarily from West Virginia. A data set of all zip code information is provided.

Discussion

Ohio River tailwater-anglers sought primarily those species related to tailwater habitats. Directed effort towards percids (24%), catfish (17%), *Morone* species (16%), and paddlefish (10%) were dominate, although in some tailwaters those anglers seeking any species exceeded species-directed anglers. Species such as centrarchids not associated with tailwater reaches were not sought or caught. Schell et al. (1996) reported that 21% of all Ohio River anglers were seeking black bass; in contrast, less than 1% of the tailwater anglers sought this species group. Schell et al. (1996) also reported that directed effort toward any species (50%) and catfish (12%) were the dominant groups in the 1992-1993 survey for the entire pool. Although no definitive tailwater directed use data are provided by Schell et al. (1996), catches of percids and *Morone* sp. were reported primarily from tailwater areas suggesting a greater use by those directed effort anglers in tailwaters.

Geographic differences of directed effort were evident with the upstream tailwater fisheries dominated by any species and percid groups, the Greenup tailwater by the *Morone* sp. group, and the J.T. Myers tailwater dominated by catfish group. It appears

that the diverse interest in these fisheries are directed by culture, abundance of a given fish species, and the presence or perception of a consumption advisory or health risk. Catfish angling is of greater importance in mid-west and southern states where catfish are often considered a trophy fish (USFWS 2003b, Burlingame and Guy 1999). TVA (1998) reported that anglers sought catfish (20%) at the Watts Bar tailwater on the Tennessee River. Both blue and channel catfish are present in downstream Ohio River tailwaters, and are often extremely abundant. In upstream tailwaters, blue catfish are uncommon or are considered extirpated. Consumption advisories have and continue to be present in the upper Ohio River with a Do Not Eat restriction for channel catfish greater than 430mm, and a six meals per year restriction of channel catfish and flathead catfish less than 430mm (WVDNR 2004). The importance of percids and *Morone* species in upstream tailwaters is partially the result of the abundance of these species as compared to other game species inhabiting tailwater reaches, the hydrologic conditions at locks and dam complexes that congregate these species, and the overall cultural importance of angling and the seasonal trends of these fisheries.

Paddlefish were only sought at the J.T. Myers and Markland tailwaters. By catch was reported at other lower river tailwaters. Directed paddlefish angling is prohibited in the Ohio-West Virginia reach of the Ohio River (WVDNR 2004), consequently no legal fishing is present. The Markland tailwater has historically been popular for paddlefish angling, and hydrologic conditions at this locks and dam complex congregate this species (Henley et al. 2002).

Angling effort (hours) was compared with previous Ohio River recreational survey. Angling effort was greatly reduced in the present survey compared to that

reported by Pierce et al. (1983), Schell et al. (1996), and ORFMT (2001). A reduction of over 50% was found for the same period in 2000 as 2002 for the New Cumberland, Pike Island, Willow Island, Greenup, and Markland tailwaters. The Greenup tailwater represented the greatest reduction with over 90% fewer hours expended in 2002 than 2000. Factors contributing to these reductions appear to be related to both water levels and security issues. Water levels were considerable higher in 2002 than 2000 resulting in loss of angling days (Figure 9). During extremely high water levels, angling success or the perception of success is diminished or safety issues become apparent. Homeland security issues following the September 11, 2001 events resulted in the temporary closure of several access points at Ohio River locks and dam complexes. This was evident at all Ohio River complexes at the lock side of the complex. In addition, a popular access area in the Greenup tailwater was closed from September 2001 through May 2002. O'Bara (1991) reported that both natural and human-induced factors may result in annual fluctuations in angler use and success, and care should be taken in the interpretation in all angler-based information.

Channel catfish catch rates were greatest at the J.T. Myers tailwater (0.68/hr) and lowest at the Willow Island tailwater (0.04/hr). Catch rates reported from the Missouri River (0.13.hr) and the Tennessee River-Watts Bar tailwater 0.02/hr) were within this range (Stanovick 1999; TVA 1998). Ohio River tailwater catch rates exceeded that found for the Tennessee River-Watts Bar tailwater from all major sport fish species (Sauger: Ohio River: 0.22—1.86/hr; Tennessee River: 0.05/hr; White bass: Ohio River: 0.75—1.22/hr; Tennessee River: 0.12/hr).

Percent of fish harvested was lowest in upstream tailwaters. Consumption advisories may be one important factor. Sauger, walleye, largemouth bass, white bass, hybrid striped bass, catfish species, freshwater drum, and common carp all have meal restriction advisories in the West Virginia-Ohio reach of the Ohio River (WVDNR 2004). This reduced harvest also was evident in angler exploitation results reported in an accompanying study.

Access appeared to be a factor affecting use by anglers residing in adjacent states. Better access is afforded on the Ohio bank at Pike Island and New Cumberland tailwaters, resulting in a greater percentage of Ohio residing anglers. In contrast, angler access is easier on the West Virginia bank of the Willow Island tailwater consequently; a higher percent of West Virginia anglers fished this tailwater. At tailwaters where easy access is on both banks, angler use by residence was similar (R.C. Byrd tailwater: Ohio 51% and West Virginia 49%). Increased public awareness of the quality of angling in Ohio River tailwaters on a more regional frame should result in attracting a greater non-resident angling public.

The influence of locks and dam complexes on recreational angling effort and catch is well-documented (TVA 1998l, Schell et al. 1996). The congregation of percids, *Morone* sp., and paddlefish directly downstream of locks and dam complexes can be attributed to both natural and human-induced conditions. True riverine conditions usually only exist in tailwater reaches (not more than a few km downstream of a locks and dam complex) in the Ohio River with a longitudinally trend towards more lenthic conditions in mid-pool and lower-pool reaches. In addition, riverine conditions conducive to riverine-species spawning are usually only found in tailwater reaches where persistent

flows promote gravel beds or allow for the buoyancy of eggs and larval fish. In addition, riverine conditions conducive to riverine-species spawning are usually only found in tailwater reaches where persistent flows promote gravel beds or allow for the buoyancy of eggs and larval fish. Therefore, these more natural lotic conditions associated with tailwater reaches promote the congregation of riverine species.

The potential inability of migratory species to pass through locks and dam complexes also encourage the congregation of riverine species in tailwater reaches. Results from the accompanying fish passage study found that greater than 50% of tagged and recovered sauger, white bass, and paddlefish at eight Ohio River pools were recaptured within the tagged-pool. This percent of non-movement increased to over 70% at those locks and dam complexes where hydraulic conditions associated with these complexes have greater impedances to fish passage. It appeared that only when extremely high river flows are present do these riverine fish species pass through dam gates. True river species such as sauger, white bass, and paddlefish consequently inhabit these tailwater reaches.

A second aspect of recreational angling associated with tailwater reaches is linked with human behavior. Access to the entire Ohio River is restrictive because of land ownership, natural conditions, and safety concerns. In most pools, bank anglers are restricted to only a few public fishing areas and to the tailwater reaches in close proximity to a lock and dam complex. Although not always high quality facilities, these tailwater fishing access areas are often the only areas that a bank angler can fish. The congregation of riverine fish especially during spawning periods result in high quality angling opportunities that are not offered throughout the Ohio River. This results in a

high density of anglers in a minimal area. Results from Schell et al. (1996) indicated that 66% of the total catch was from that tailwaters which only comprised 1% of available angling habitat in the Ohio River. Although only tailwater anglers were interviewed in this present study, it is believed that tailwater reaches do contribute to a majority of angling in the Ohio River.

Fishery managers are often concerned when both anglers and fish congregate leading to a potential for overexploitation of a given species or conflicts of angler directed groups. Tailwater fisheries in the Ohio River are such a situation. Large numbers of anglers are seeking a congregation of fish over a defined period of time. These conditions are usually in the late-fall through early-spring for percids, *Morone* species, and paddlefish.

Regulations are one technique to reduce harvest and moderate exploitation. The Ohio River paddlefish recreational fishery is restricted by season and bag limits, as well as a closed season in the upper river. The Ohio River percid fishery is subjected to a bag limit (10 fish per day) with no size and season restrictions; and a bag and size limit is imposed on the *Morone* species fishery.

A second more natural factor in reducing overexploitation is the natural hydrologic conditions of the Ohio River. In 2002 and 2003, high river flows reduced angling effort primarily due to safety concerns and access problems. These low angling effort periods induced by river conditions appear to provide a natural refugia for a seasonal fishery such as percids, *Morone* species, and paddlefish. Total effort was reduced by greater than 50% during these high water seasons as compared to low or normal seasons (ORFMT 2001).

The percid community is one of concern. Study results suggest that sauger and walleye do congregate downstream of locks and dam complexes, their passage is restrictive by locks and dam complexes especially in the upper river, and are sought after by anglers. ORFMT (2004) found that although angler annual exploitation is relatively low (13% river-wide), annual mortality is high (greater than 60% for ages 1-5). Several factors may be contributing to the high annual mortality including natural factors, delayed angling-associated mortality, and human-induced stressors. These factors will be addressed in future ORFMT sponsored studies.

The linkage between locks and dam complexes, fish passage issues, the elimination of vast riverine habitat due to locks and dam complexes in navigational waterways, and recreational fishing is well-documented. Tailwaters reaches are important in providing angling opportunities in large navigational waterways, but also congregate certain fish species during critical periods. This assimilation of anglers and fish at a limited time and geographic location does promote the potential for adverse affects on fish populations. It is hoped that through wise fishery and water management, this potential can be reduced.

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Table 1. Percent of directed effort for anglers from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

	Percent					
Tailwater	**Percid**	**Black Bass**	**Morone**	**Catfish**	**Paddlefish**	**Anything**
New Cumberland	27.3	2.3	9.1	2.9	0.0	58.4
Pike Island	22.0	3.7	7.4	7.6	0.0	59.3
Willow Island	26.5	0.3	23.8	3.2	0.0	46.2
R.C. Byrd	47.6	0.0	3.9	3.4	0.0	45.1
Greenup	18.8	0.3	43.9	6.8	0.0	30.2
Markland	13.9	0.0	9.9	16.8	42.9	16.5
McAlpine	35.3	0.0	11.5	9.7	0.0	43.5
J.T. Myers	22.2	0.0	12.6	57.2	2.4	5.6

Table 2. Estimated angling effort by month for all anglers from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

	Estimated Hours								
Month Year	J.T. Myers	McAlpine	Markland	Greenup	R.C. Byrd	Willow Island	Pike Island	New Cumberland	Monthly Total
Sept 01				1,941			1,168	231	3,340
Oct 01	264	62		1,384	1,414	2,201	1,496	299	7,120
Nov 01	227	3,041		2,522	2,450	1,839	2,543	860	13,482
Dec 01	47	1,431		2,799	1,203	1,852	1,778	560	9,670
Jan 02	1,021	2,368		92	754	632	543	174	5,584
Feb 02	1,279	3,004	1,208	114	626	1,234	144	255	7,864
Mar 02	330	1,568	1,838	325	432	1,171	649	322	6,635
Apr 02	38	361	1,549	424	806	1,330	804	443	5,755
May 02	170	570	731	555	933	1,561	1,435	687	6,642
Jun 02	2,548	4,064	2,128	3,899	2,529	3,946	1,443	1,295	21,852
Jul 02	4,324	4,582	1,734	3,097	3,241	1,601	2,902	923	22,404
Aug 02	2,492	3,430	2,233	2,089	1,224	2,822	1,328	859	16,477
Sept 02	1,352	2,390	1,636	2,415	840	2,252	770	140	11,795
Oct 02	622	2,207	1,572			1,194			5,595
Nov 02	485	1,239	579						2,303
Dec 02	382		311						693
Jan 03	168	697	16						881
Feb 03	992	297	887						2,176
Total	16,741	31,311	16,422	21,656	16,452	23,635	17,003	7,048	150,268

Table 3. Catch rate (#/hr) for directed effort species angling groups for selected species from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

Tailwater	Catch Rate (#/hr)					
	Sauger	All Percid	Hybrid Striped Bass	White Bass	Channel Catfish	Paddlefish
New Cumberland	0.91	1.02	0.30	0.37	0.32	
Pike Island	1.86	1.89	0.40	1.28	0.36	
Willow Island	0.59	0.68	0.90	0.79	0.04	
R.C. Byrd	1.18	1.25	0.19	0.88	0.48	
Greenup	1.48	1.64	1.76	0.61	0.40	
Markland	0.22	0.22	0.89	0.28	0.18	0.20
McAlpine	0.92	0.92	0.50	0.23	0.37	
J.T. Myers	1.30	1.30	0.62	0.08	0.68	0.19

Table 4. Estimated number harvested (H), released (R), and percent harvested by years for selected species from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

2001												
	Sauger		White Bass		Hybrid Striped Bass		Paddlefish		Channel Catfish		Blue Catfish	
Tailwater	H	R	H	R	H	R	H	R	H	R	H	R
New Cumberland	93	1,237	40	506	7	253	0	0	0	99	0	0
Pike Island	956	10,948	109	4,419	8	329	0	0	9	105	0	0
Willow Island	6	1,910	0	658	15	1,280	0	0	0	227	0	0
R.C. Byrd	1,744	3,921	36	149	0	7	0	0	0	259	0	0
Greenup	2,969	3,076	56	1,284	12	1,239	0	0	35	276	0	24
McAlpine	1,189	1,881	0	104	0	0	0	0	0	117	0	8
Myers	1,377	72	2,060	68	73	68	2	0	21	0	275	9
Total No.	8,334	23,045	2,301	7,188	115	3,176	2	0	65	1,083	275	41
2002												
	Sauger		White Bass		Hybrid Striped Bass		Paddlefish		Channel Catfish		Blue Catfish	
Tailwater	H	R	H	R	H	R	H	R	H	R	H	R
New Cumberland	80	0	278	962	166	360	0	0	26	206	0	0
Pike Island	36	599	24	3,003	40	753	0	0	53	316	0	0
Willow Island	286	1,667	0	1,956	81	4,579	0	0	27	560	0	0
R.C. Byrd	143	313	37	1,123	0	833	0	0	117	1,042	0	10
Greenup	102	1,043	0	4,782	33	11,762	0	0	70	765	0	15
Markland	170	193	79	952	151	3,381	832	3	29	102	44	417
McAlpine	4,331	2,036	95	461	137	1,272	47	165	499	1,064	57	234
Myers	1,628	851	223	60	178	59	550	0	1,552	224	4,588	843
Total No.	6,776	6,702	736	13,299	786	22,999	1,429	168	2,373	4,279	4,689	1,519
2003												
	Sauger		White Bass		Hybrid Striped Bass		Paddlefish		Channel Catfish		Blue Catfish	
Tailwater	H	R	H	R	H	R	H	R	H	R	H	R
Markland	0	0	0	0	0	0	32	0	0	0	0	0
McAlpine	164	54	0	0	0	0	16	0	0	0	0	0
Myers	430	353	0	0	0	0	414	3	16	11	146	0
Total No.	594	407	0	0	0	0	462	3	16	11	146	0
2001-2003 Total	15,704	30,154	3,037	20,487	901	26,175	1,893	171	2,454	5,373	5,110	1,560
Percent Harvest	34		13		3		92		31		77	

Table 5. Percent of state of residence for anglers from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

	States							
Tailwater	**AL**	**IL**	**IN**	**KY**	**OH**	**WV**	**PA**	**NY**
New Cumberland	0	0	0	0	81	17	2	0
Pike Island	0	0	0	0	76	22	1	1
Willow Island	1	0	0	0	9	89	0	0
R.C. Byrd	0	0	0	0	51	49	0	0
Greenup	0	0	0	38	63	0	0	
Markland	0	0	75	19	6	0	0	0
McAlpine	0	0	40	60	0	0	0	0
J.T. Myers	0	24	6	70	0	0	0	0

	Time Period																	
	2001				2002												2003	
Tailwater	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
New Cumberland																		
Pike Island																		
Willow Island																		
R.C. Byrd																		
Greenup																		
Markland																		
McAlpine																		
J.T. Myers																		
					Tailwater Creel Survey Period													
					Tailwater Creel and Paddlefish Recovery Survey													
					Paddlefish Recovery Survey													

Figure 1. Monthly activity of data collection activities for a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

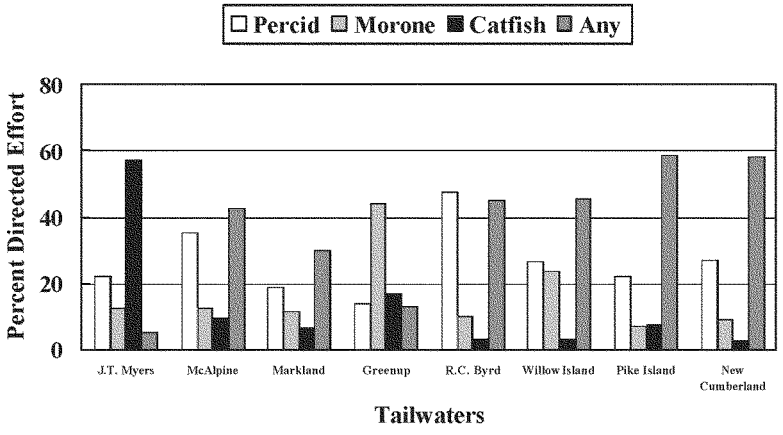

Figure 2. Percent directed effort for four groups from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

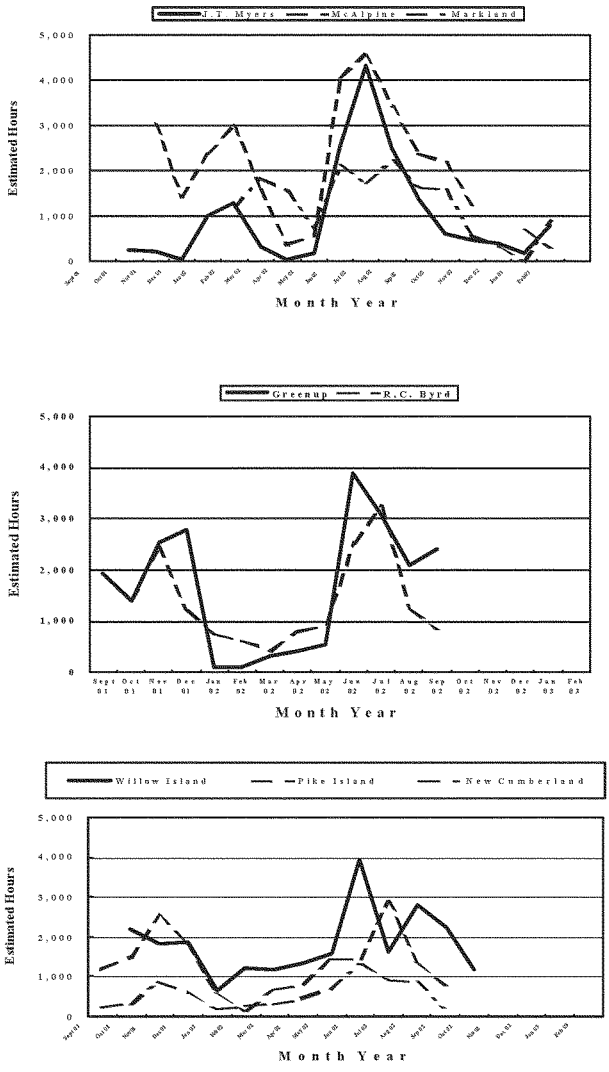

Figure 3. Estimated angling effort (hours) by month from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

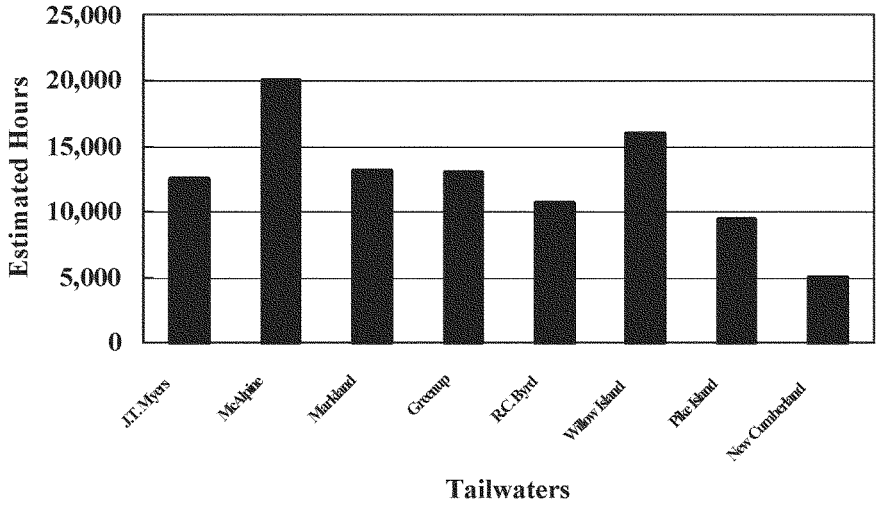

Figure 4. Estimated angling effort (hours) from February 2002 through September 2002 from a recreational angling survey of eight Ohio River tailwaters.

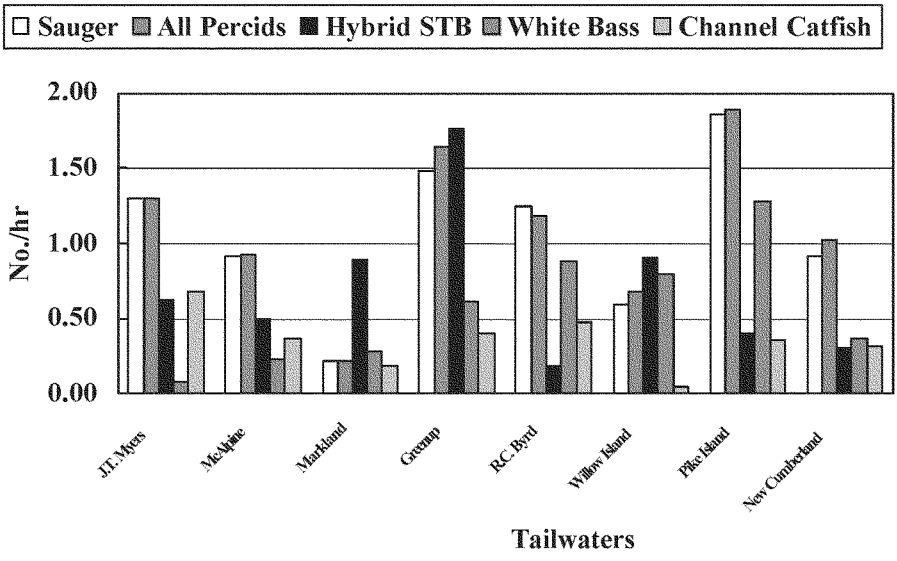

Figure 5. Catch rate (#/hr) for directed effort species angling groups for selected species from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

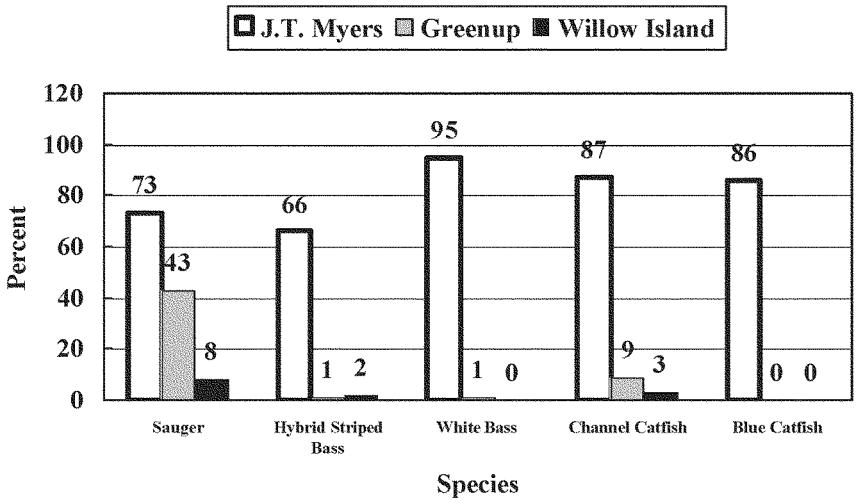

Figure 6. Percent harvested by species for three representative tailwaters from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

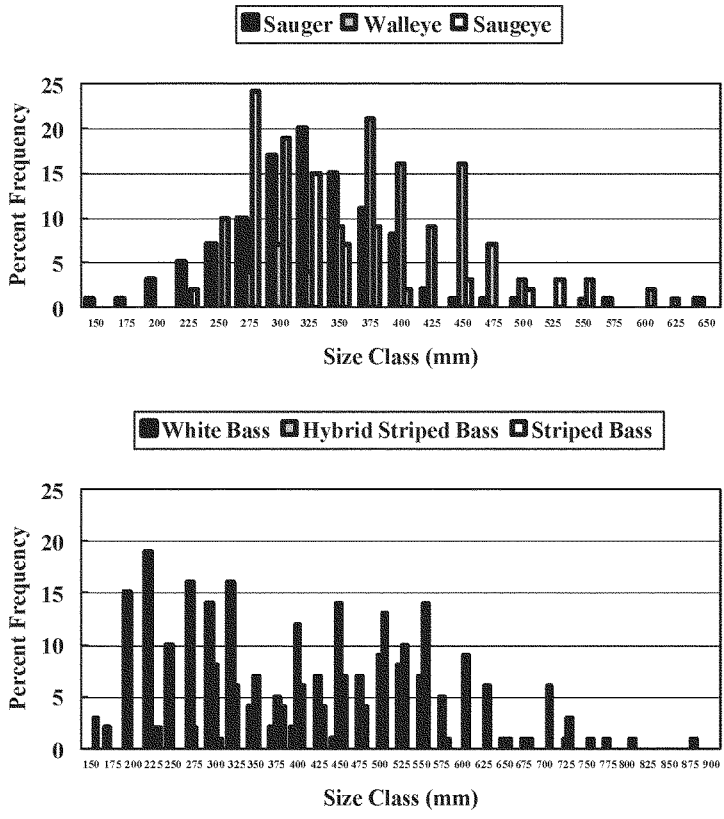

Figure 7. Length frequency distribution for harvested percids and *Morone* species group from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

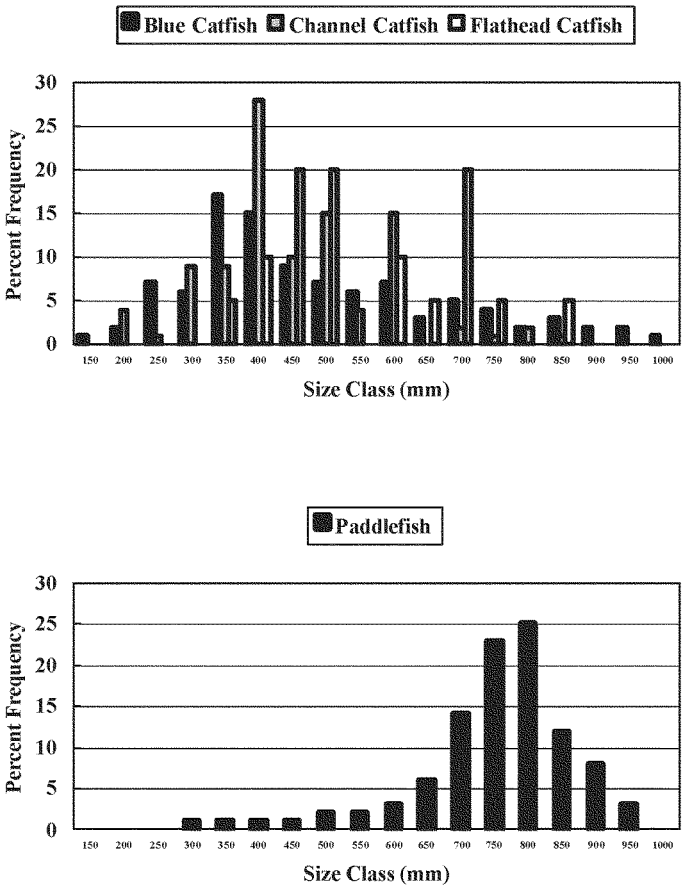

Figure 8. Length frequency distribution for harvested catfish species and paddlefish and from a recreational angling survey of eight Ohio River tailwaters. 2001-2003.

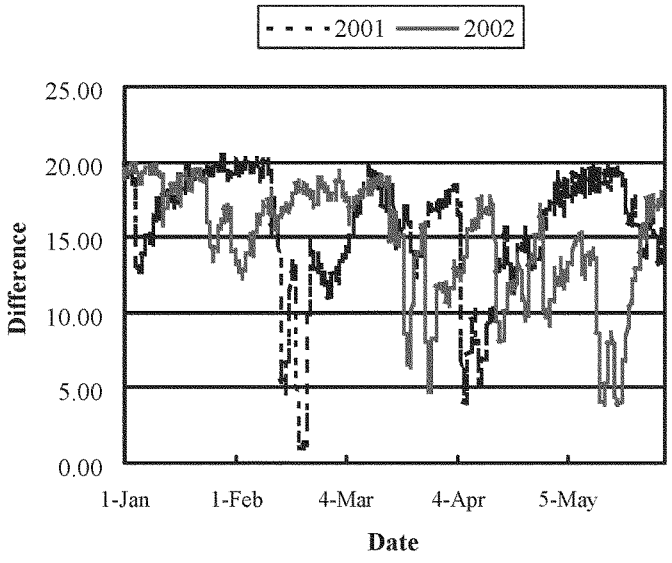

Figure 9. River stage differences (upstream-downstream) for the Willow Island Locks and Dam complex of the Ohio River. January through May 2001 and 2002.

Chapter 5

Ohio River Mainstem System Study (ORMSS)

Presence of Glochidial Infestation on Ohio River Species Task

Introduction

Freshwater mussels exhibit a highly specialized life history in that modified larvae, glochidia, experience a period as an obligate parasite on the gills, fins, and potentially other external structures of fish. Female mussels brood glochidia until mature, and then release these larvae either singly or in clusters through their siphons. Released glochidia must encounter a suitable fish host, become encysted for a period of time while metamorphosing into juvenile mussels, and finally release from the fish host. If suitable fish hosts are not encountered, the glochidia will be rejected (Kat 1984).

Knowledge of fish host and infestation rates is essential in the conservation of North American mussel fauna (Haag and Warren 1997). Many fish host studies have been conducted in a laboratory environment where potential fish hosts are either directly or indirectly infested with glochidia (Watters and O'Dee. 1998). Others investigators have used a field-based approach and examined potential fish hosts collected in a more natural environment (Neeves and Widlak 1988, Weiss and Layzer 1995). In many of these studies low infestation rates have hampered the investigators ability to gain an understanding of host-glochidia relationship.

The decline of the North American freshwater mussel fauna is well-documented (Williams et al. 1993). Human-induced alterations from a suite of activities have reduced

mussel populations throughout the native range. Dams, through altering flow regimes, have caused the extirpation of 30%-60% of the native mussel species in selected United States rivers (Williams et al. 1992). Competition from non-endemic mollusks has also lead to the decline in native mussel fauna. Zebra mussels have increased their range from early colonization in the Great Lakes to throughout the Mississippi River basin. These range extensions have often been linked to commercial navigation uses.

Concern for native freshwater mussel populations in the Ohio River sub-basin and the potential influence of commercial navigation and locks and dam complexes resulted in the proposing of a study to at least minimally address some potential issues. The infestation of potential fish hosts and the problems associated with fish passage on the Ohio River was one aspect proposed to be addressed.

Specific objectives were:

11. To determine infestation rates of a wide diversity of Ohio River fish species, and
12. To ascertain potential impacts of fish passage problems associated with infested fish species.

Approach

Fish were collected using pulsed DC boat-mounted electrofishing equipment at selected locations throughout the Ohio River sub-basin. Fish were initially held for up to 10-minutes in an aerated live-well during collection tasks. At the end of collection period, fish were placed in individual plastic bags, the bags placed on ice, and returned to the laboratory for processing. Once at the laboratory, fish were identified to species, measured to total length, and dissected. Gills and fins were removed, and placed in individual coded bags containing 95% denatured ethyl alcohol.

Samples (gills and fins) were held for no more than 3-months prior to examinations. Initially, all samples (individual fish) were examined for the presence and/or absence of glochidia, but with the low number of glochidia found in initial examinations, samples were then randomly selected. Using a random selection process, it was attempted to examine at least 40% of all samples by fish species and location. This was instituted after consultation with U.S. Army corps of Engineers and U.S. Fish and Wildlife Service project reviewers.

Tissue (fins and gills) were washed with distilled water and placed in a sodium hydroxide solution (N/50) for up to one week to allow for clearing of glochidia. Investigators used a dissecting scope to determine the presence and/or absence of glochidia on all tissue. If potential glochidia were noted, glochidia were excised, placed in tissue vials containing 95% denatured ethyl alcohol and sent for further review to a trained malacologist. Upon confirmation, the glochidia were sent to Ohio State University Museum of Biological Diversity for species identification.

A data base was developed using *Microsoft Excel* to manage all information. Information on the fish species examined, location of capture, date of capture, and presence/absence of glochidia were included in the database. At the conclusion of the task, this information was linked with the GIS data base developed in an accompanying task.

Results

Fish were collected from 10 different locations within the Ohio River (Table 1). The most downstream location was the J.T. Myers tailwater (ORM 850) and the most upstream location was the New Cumberland tailwater (ORM 55). Most collections were made in tailwater reaches because of the potential presence of freshwater mussels in these

free-flowing sections, and the congregation of fish species just downstream of the locks and dam complexes. One location, Belleville Pool at Blennerhassett Island (ORM 185.5), was selected because of the known presence of freshwater mussels in this area. One additional location was selected, Kanawha River-Winfield tailwater (KRM 32), because of the movement of many fish species from the Ohio River upstream to the first locks and dam complex on this major tributary.

Collections were made at all four seasons and under varying water temperature and flow conditions. It was thought that fish might be predestined to move during elevated water levels and flows, thus collections were made during a few high water events.

Thirty-one fish species were collected representing a wide range of behavioral and habitat guilds (Table2). Taxonomically, these 31 species represented 12 families and over 20 genera. Common large river species included the gizzard shad, freshwater drum, redhorses, sauger, and white bass. Non-endemic species included the grass carp, common carp, saugeye, and hybrid striped bass. Uncommon species included the blue sucker and goldeye.

One-thousand and sixty-seven individuals were processed (identified, measured, and dissected). Of these, 536 were examined for the presence of glochidia (Table 2). All samples taken in the winter and spring were examined, as were 64% of the summer samples, and 42% of the fall samples (Table 3 and 4). Only gizzard shad (84 of 307, 27%) were examined at a less than the 40% criteria of common species. Other less common species that were examined at less than 40% were longear sunfish (1 of 4) and

logperch (3 of 10). Samples from all locations except the Belleville tailwater (37%) were examined at the 40% criteria.

Four fish (<1%) were found to be infested with glochidia. These included three individuals from the R.C. Byrd tailwater collection in June 2002 and one individual from the J.T. Myers tailwater collection in October 2002. Fish species infested were longnose gar, gizzard shad, and skipjack herring from the R.C. Byrd tailwater collection, as well as a spotted bass from the J.T. Myers tailwater collection. No additional fish were found to be infested from May and October collections at the R.C. Byrd tailwater.

Seasonally, no fish were found to be infested in either the summer or winter collections, less than 1 percent in the fall, and 4 percent in the spring. No differences were detected at varying water levels or flows.

Discussion

The low number of fish found to be infested with glochidia during the survey limits any meaningful analysis. Similar low infestation rates have been found in several river systems including the Green River, a major tributary to the Ohio River (Weiss and Layzer 1995).

Seasonally, glochidia were found in both the spring (June) and fall (October). Several investigations have proposed reproductive models that suggest freshwater mussels are reproductively active throughout the year. Early investigators suggested two strategies, a winter and summer period when glochidia would be present in the marsupia (Skerki 1895). More recently, several investigators have reported the presence of glochidia infested on fish during all seasons, as well as the presence of glochidia in the water column (Jansen 1991, Weiss and Layzer 1995, Neeves and Widlak 1988). Watters

and O'Dee (2000) suggested that timing of glochidial release was water temperature dependent resulting in releases from May through October.

Although the knowledge of fish host is lacking for many freshwater mussels, the fish species found to be infested in this study have been found to serve as hosts (Haag and Warren 1997). Longnose gar, gizzard shad, skipjack herring, and spotted bass also have been reported to serve as host for species of Ohio River mussels (OSU Division of Mollusks-Host Database).

The presence of glochidia in free ranging fishes is problematic because of the natural low rate of infestation. If fish passage issues do exist in relation to glochidia infestation and leading to the decline of unionid populations, it is suggested that a more informative approach may be the modeling of potential fish hosts and their association with high-lift dams and passage mechanisms.

Passage through high-lift dams by species such as sauger, walleye, white bass, and paddlefish were found to be at least minimally restricted in the present study. Knight et al. (2002) suggested that fish passage is a problem at many Ohio River high-lift dams except at high flows and open river conditions. These modeled predictions (Knight et al. 2002) were correlated with results found in the present study. Study findings strongly suggest that sauger moved only during open water periods. Open water conditions only were present at less than 5% of the years modeled for all complexes upstream of the Racine Locks and Dam Complex. In contrast, this condition was achieved for 50% of the years modeled at the J.T. Myers and Newburgh complex (Knights et al. 2002). If glochidial infestation is not present during these open water periods and fish host species are not in the vicinity of the locks and dam complex, it appears unlikely that glochidia

will pass through high-lift dams via fish. The extremely low infestation rate (<1%) found in this study suggests that these conditions are not readily achievable.

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Table 1. Collection locations, pools and dates, the number of fish processed and examined, and number of fish with glochidia present from a survey conducted within the Ohio River sub-basin, 2002.

Collection Location	Collection Pool	Collection Date	Number		Number of Fish Glochidia Present
			Processed	Examined	
Belleville Tailwater	Racine	08/13/02	71	26	0
Belleville Pool-ORM 185.5	Belleville	09/30/02	132	31	0
Greenup Tailwater	Meldahl	06/12/02	9	9	0
Greenup Tailwater	Meldahl	10/21/02	165	77	0
J.T. Myers Tailwater	Smithland	10/29/02	75	48	1
Markland Tailwater	McAlpine	10/30/02	75	29	0
New Cumberland Tailwater	Pike Island	05/30/02	9	9	0
Pike Island Tailwater	Hannibal	03/07/02	21	21	0
Pike Island Tailwater	Hannibal	10/07/02	113	66	0
R.C. Byrd Tailwater	Greenup	05/02/02	29	29	0
R.C. Byrd Tailwater	Greenup	06/04/02	31	31	3
R.C. Byrd Tailwater	Greenup	10/10/02	159	32	0
Winfield Tailwater	R.C. Byrd	08/28/02	55	55	0
Willow Island Tailwater	Belleville	10/03/02	123	73	0
		Total	1067	536	4

Table 2. The number of individual fish processed and examined, and number of fish with glochidia present by species from a survey conducted within the Ohio River sub-basin, 2002.

Fish Species	Number		Percent Examined	Number Glochidia Present	Percent Glochidia Present
	Processed	Examined			
Blue Sucker	1	1	100	0	0
Northern Hogsucker	2	2	100	0	0
Quillback	29	20	69	0	0
River Redhorse	22	12	55	0	0
Shorthead Redhorse	80	44	55	0	0
Smallmouth Buffalo	79	33	42	0	0
Black Crappie	9	6	67	0	0
Bluegill	16	8	50	0	0
Green Sunfish	3	2	67	0	0
Largemouth Bass	39	22	56	0	0
Longear Sunfish	4	1	25	0	0
Redear Sunfish	2	1	50	0	0
Smallmouth Bass	26	20	77	0	0
Spotted Bass	15	11	73	1	9
White Crappie	8	6	75	0	0
Gizzard Shad	307	84	27	1	1
Skipjack Herring	50	27	54	1	4
Common Carp	15	8	53	0	0
Grass Carp	1	1	100	0	0
Goldeye	1	1	100	0	0
Channel Catfish	21	12	57	0	0
Flathead Catfish	43	18	42	0	0
Hybrid Striped Bass	42	23	55	0	0
Striped Bass	27	20	74	0	0
White Bass	44	34	77	0	0
Logperch	10	3	30	0	0
Sauger	73	60	82	0	0
Saugeye	3	3	100	0	0
Walleye	3	2	67	0	0
Freshwater Drum	55	26	47	0	0
Longnose Gar	37	25	68	1	4
Total	1067	536	50	4	1

Table 3. The number of individual fish processed by species from specific locations from a survey conducted within the Ohio River sub-basin, 2002.

	Number of Fish Processed			
	New Cumberland	Pike Island	Pike Island	Willow Island
	Tailwater	Tailwater	Tailwater	Tailwater
Species	May-02	Mar-02	Oct-02	Oct-02
Black Crappie	0	0	1	1
Bluegill	0	0	4	2
Blue Sucker	0	0	0	0
Channel Catfish	1	2	2	1
Common Carp	0	0	2	2
Flathead Catfish	0	0	5	7
Freshwater Drum	0	0	1	9
Gizzard Shad	0	0	45	33
Goldeye	0	0	0	0
Grass Carp	0	0	0	0
Green Sunfish	0	0	0	0
Northern Hogsucker	0	0	2	0
Hybrid Striped Bass	1	2	2	0
Largemouth Bass	0	0	6	5
Logperch	0	0	0	0
Longnose Gar	0	0	3	3
Longear Sunfish	0	0	2	0
Quillback	0	0	0	1
Redear Sunfish	0	0	0	0
River Redhorse	0	0	0	0
Sauger	3	10	0	0
Saugeye	0	0	0	0
Shorthead Redhorse	0	0	10	21
Skipjack Herring	0	0	3	5
Smallmouth Bass	2	1	6	3
Smallmouth Buffalo	0	0	14	7
Spotted Bass	0	0	2	0
Striped Bass	0	0	0	0
Walleye	0	0	1	0
White Bass	2	6	2	22
White Crappie	0	0	0	1
Total	9	21	113	123

Table 3. continued.

	Number of Fish Processed				
	Belleville Tailwater	Belleville Pool ORM 185.5	Winfield Tailwater	R.C. Byrd Tailwater	R.C. Byrd Tailwater
Species	Aug-02	Sep-02	Aug-02	May-02	Jun-02
Black Crappie	1	1	1	0	0
Bluegill	1	1	3	0	0
Blue Sucker	0	0	0	0	0
Channel Catfish	0	0	3	0	3
Common Carp	3	0	0	2	2
Flathead Catfish	2	10	4	0	2
Freshwater Drum	6	2	7	0	7
Gizzard Shad	11	71	8	6	5
Goldeye	0	0	0	0	0
Grass Carp	0	0	0	0	0
Green Sunfish	0	0	0	0	0
Northern Hogsucker	0	0	0	0	0
Hybrid Striped Bass	2	0	1	0	2
Largemouth Bass	0	7	0	0	0
Logperch	0	2	1	0	0
Longnose Gar	2	0	2	1	8
Longear Sunfish	0	0	1	0	0
Quillback	11	0	0	8	0
Redear Sunfish	0	0	0	0	0
River Redhorse	0	0	0	5	0
Sauger	0	3	0	6	0
Saugeye	0	0	0	1	0
Shorthead Redhorse	7	16	7	0	0
Skipjack Herring	0	2	12	0	2
Smallmouth Bass	5	5	0	0	0
Smallmouth Buffalo	19	7	2	0	0
Spotted Bass	1	5	1	0	0
Striped Bass	0	0	0	0	0
Walleye	0	0	0	0	0
White Bass	0	0	2	0	0
White Crappie	0	0	0	0	0
Total	71	132	55	29	31

Table 3. continued.

	Number of Fish Processed				
	R.C. Byrd	Greenup	Greenup	Markland	J.T. Myers
	Tailwater	Tailwater	Tailwater	Tailwater	Tailwater
Species	Oct-02	Jun-02	Oct-02	Oct-02	Oct-02
Black Crappie	0	0	4	0	0
Bluegill	0	0	3	0	2
Blue Sucker	0	0	0	1	0
Channel Catfish	0	1	3	2	3
Common Carp	0	0	0	0	4
Flathead Catfish	10	0	2	0	1
Freshwater Drum	5	0	11	1	6
Gizzard Shad	71	2	23	26	6
Goldeye	1	0	0	0	0
Grass Carp	0	0	0	0	1
Green Sunfish	0	0	0	0	3
Northern Hogsucker	0	0	0	0	0
Hybrid Striped Bass	11	1	7	12	1
Largemouth Bass	13	0	1	2	5
Logperch	4	0	3	0	0
Longnose Gar	7	0	6	4	1
Longear Sunfish	1	0	0	0	0
Quillback	0	0	5	0	4
Redear Sunfish	0	0	1	0	1
River Redhorse	0	0	8	7	2
Sauger	0	4	35	3	9
Saugeye	0	0	2	0	0
Shorthead Redhorse	16	0	3	0	0
Skipjack Herring	1	0	9	7	9
Smallmouth Bass	1	1	0	2	0
Smallmouth Buffalo	11	0	14	4	1
Spotted Bass	0	0	0	0	6
Striped Bass	0	0	20	2	5
Walleye	0	0	1	1	0
White Bass	7	0	1	0	2
White Crappie	0	0	3	1	3
Total	159	9	165	75	75

Table 4. The number of individual fish examined by species from specific locations from a survey conducted within the Ohio River sub-basin, 2002.

	Number of Fish Examined			
	New Cumberland Tailwater	Pike Island Tailwater	Pike Island Tailwater	Willow Island Tailwater
Species	May-02	Oct-02	Oct-02	Mar-02
Black Crappie	0	1	1	0
Bluegill	0	1	2	0
Blue Sucker	0	0	0	0
Channel Catfish	1	0	0	2
Common Carp	0	1	0	0
Flathead Catfish	0	4	3	0
Freshwater Drum	0	4	0	0
Gizzard Shad	0	22	16	0
Goldeye	0	0	0	0
Grass Carp	0	0	0	0
Green Sunfish	0	0	0	0
Northern Hogsucker	0	0	2	0
Hybrid Striped Bass	1	0	2	2
Largemouth Bass	0	3	6	0
Logperch	0	0	0	0
Longnose Gar	0	3	3	0
Longear Sunfish	0	0	0	0
Quillback	0	1	0	0
Redear Sunfish	0	0	0	0
River Redhorse	0	0	0	0
Sauger	3	0	0	10
Saugeye	0	0	0	0
Shorthead Redhorse	0	11	8	0
Skipjack Herring	0	5	3	0
Smallmouth Bass	2	2	6	1
Smallmouth Buffalo	0	0	10	0
Spotted Bass	0	0	1	0
Striped Bass	0	0	0	0
Walleye	0	0	1	0
White Bass	2	14	2	6
White Crappie	0	1	0	0
Total	9	73	66	21

Table 4. continued.

	Number of Fish Examined				
	Belleville Tailwater	Belleville Pool ORM 185.5	Winfield Tailwater	R.C. Byrd Tailwater	R.C. Byrd Tailwater
Species	Aug-02	Sep-02	Aug-02	May-02	Jun-02
Black Crappie	1	1	1	0	0
Bluegill	0	0	3	0	0
Blue Sucker	0	0	0	0	0
Channel Catfish	0	0	3	0	3
Common Carp	1	0	0	2	2
Flathead Catfish	2	3	4	0	2
Freshwater Drum	1	2	7	0	7
Gizzard Shad	2	3	8	6	5
Goldeye	0	0	0	0	0
Grass Carp	0	0	0	0	0
Green Sunfish	0	0	0	0	0
Northern Hogsucker	0	0	0	0	0
Hybrid Striped Bass	0	0	1	0	2
Largemouth Bass	0	3	0	0	0
Logperch	0	0	1	0	0
Longnose Gar	0	0	2	1	8
Longear Sunfish	0	0	1	0	0
Quillback	5	0	0	8	0
Redear Sunfish	0	0	0	0	0
River Redhorse	0	0	0	5	0
Sauger	0	1	0	6	0
Saugeye	0	0	0	1	0
Shorthead Redhorse	3	8	7	0	0
Skipjack Herring	0	2	12	0	2
Smallmouth Bass	3	3	0	0	0
Smallmouth Buffalo	7	2	2	0	0
Spotted Bass	0	3	1	0	0
Striped Bass	0	0	0	0	0
Walleye	0	0	0	0	0
White Bass	1	0	2	0	0
White Crappie	0	0	0	0	0
Total	26	31	55	29	31

Table 4. continued.

	Number of Fish Examined				
	R.C. Byrd	Greenup	Greenup	Markland	J.T. Myers
	Tailwater	Tailwater	Tailwater	Tailwater	Tailwater
Species	Oct-02	Jun-02	Oct-02	Oct-02	Oct-02
Black Crappie	0	0	1	0	0
Bluegill	0	0	1	0	1
Blue Sucker	0	0	0	1	0
Channel Catfish	0	1	0	1	1
Common Carp	0	0	0	0	2
Flathead Catfish	0	0	0	0	0
Freshwater Drum	1	0	0	1	3
Gizzard Shad	4	2	11	3	2
Goldeye	1	0	0	0	0
Grass Carp	0	0	0	0	1
Green Sunfish	0	0	0	0	2
Northern Hogsucker	0	0	0	0	0
Hybrid Striped Bass	2	1	5	6	1
Largemouth Bass	4	0	1	2	3
Logperch	2	0	0	0	0
Longnose Gar	2	0	3	2	1
Longear Sunfish	0	0	0	0	0
Quillback	0	0	2	0	4
Redear Sunfish	0	0	0	0	1
River Redhorse	0	0	3	2	2
Sauger	0	4	24	3	9
Saugeye	0	0	2	0	0
Shorthead Redhorse	6	0	1	0	0
Skipjack Herring	1	0	0	2	0
Smallmouth Bass	1	1	0	1	0
Smallmouth Buffalo	4	0	6	2	0
Spotted Bass	0	0	0	0	6
Striped Bass	0	0	15	1	4
Walleye	0	0	0	1	0
White Bass	4	0	1	0	2
White Crappie	0	0	1	1	3
Total	32	9	77	29	48

AQUATIC STUDIES

EXHIBIT D

SUMMARY OF
OSU MUSSEL DATABASE

FISH PASSAGE STUDY CONDUCTED FOR ORMSS – DISTRIBUTION OF MUSSELS AND FISH WITHIN THE OHIO RIVER

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Background

Mussel – Fish Host Associations

Minute bivalved larvae, or glochidia, develop over a period of days to months, depending on water temperature and species. Glochidia are a type of specialized veliger larvae. Freshwater mussels, and freshwater molluscs in general, lack the trochophore larva so common to marine molluscs. When first discovered by Leeuwenhoek in 1697, glochidia were considered by some (but not by Leeuwenhoek) to be parasites living in the mussel's gills, and were given the scientific name *Glochidium parasiticum* by Rathke (1797). For nearly three quarters of a century, a lively debate ensued as to whether these 'agglomerations of animicules,' as Prévost called them (1826), were mussel parasites or mussel larvae. Leydig (1866) appears to have been the first to identify glochidia on fishes, and Braun (1878a,b) experimentally demonstrated their parasitic role and their true identity as larval mussels.

North American freshwater mussels are historically divided into two behavioral groups based upon the duration that glochidia are held in the marsupia. Tachytictic, or short-term, breeders spawn in the spring or summer and release their glochidia later the same year, usually by July or August. Bradytictic, or long-term, breeders spawn in the summer or early autumn, form glochidia, and typically hold these larvae in the marsupium until the following spring or summer. There is evidence that glochidia that overwinter till spring in the marsupium experience less mortality once on the host than those glochidia of the same species that are released in the autumn and metamorphose that same year (Corwin, 1921; Higgins, 1930; Tedla & Fernando, 1969; Zale & Neves, 1982). But some otherwise "bradytictic" individuals release glochidia in autumn or winter

to overwinter on their hosts. They remain dormant on their host until a threshold temperature is reached the following spring, at which time they metamorphose and excyst (Watters & O'Dee, 1999). Some species, such as *Pyganodon grandis* and *Leptodea fragilis*, apparently utilize host-overwintering glochidia as part of their normal life history. The ability to overwinter on hosts is related to the duration the glochidia spend attached to the host, with overwintering success declining with time. Overwintering of glochidia on hosts may aid in dispersal of the species, and confer greater fitness on those glochidia capable of remaining attached till spring. Whether these glochidia overwinter in the marsupia or on their hosts, this prolonged developmental stage may be necessary for bradytictic species. There is mounting evidence that some temperate species have multiple broods. In these cases, a species may have both tachytictic (in the summer) and bradytictic (over winter) reproduction. Approximate gravid periods for Ohio River mussel species are given in Appendix B, where known.

Nearly all freshwater mussels are obligate vertebrate parasites as larvae. Of the approximately 300 species in North America, only one, the salamander mussel *Simpsonaias ambigua,* is believed to use exclusively a non-fish host, the mudpuppy *Necturus maculosus* (Howard, 1915, 1951). The remainder are believed to use fishes, but may be capable of parasitizing amphibians as well (Watters, 1997a; Watters & O'Dee, 1998). Although claims have been made that several species may complete their metamorphosis without a host (Lefevre & Curtis, 1911; Howard, 1914b), evidence suggests that most North American mussels must parasitize a host to complete their life cycle. Only one North American species (Barfield & Watters, 1998; Lellis & King, 1998), an African mutelid species (Kondo, 1990), and several South American mussels (Mansur & Campos-Velho, 1990) are known to bypass the parasitic stage completely.

Hosts are infested with glochidia when they come into contact with them in the water, on the substrate, or by attempting to ingest them. Different mussel species have different methods of releasing these larvae. Some simply expel the glochidia along with water and waste products. Hosts either take in suspended glochidia and pass them over their gills, where they attach, or they contact larvae on the substrate, where the parasites attach to the fins or skin. Some mussels, such as *Anodonta suborbiculata, Anodontoides ferussacianus,* and *Utterbackia imbecillis*, release "webs" or "trot lines" of mucus containing glochidia that ensnare passing fishes (Hove et al., 1995; Watters & O'Dea, 1997d). Other mussels bind glochidia into matrices called conglutinates (Chamberlain, 1934; Fuller, 1971). Several types of conglutinates have been identified. The simplest are formed entirely of glochidia, each enclosed in a fragile envelope. A more complex type is formed from eggs and glochidia. In these, the majority of the mass is composed of sterile eggs. In some species up to 85% of the total number of eggs have this structural, rather than reproductive, function, and apparently are never destined to be fertilized (Barnhart, 1997). The eggs function to give shape and color to the entire mass, which has functional glochidia imbedded in it or attached to it. Another type of conglutinate, found in *Strophitus undulatus*, is composed of a mucus rod containing the glochidia. When released by the female, the glochidia squeeze through pores in the conglutinate wall and move to the outside (Watters, 2002). Other conglutinates are even more complex, such as

the "fish-fry" lures of *Ptychobranchus fasciolaris*, which are multi-layer constructions complete with discrete pigmented areas and adhesive pads (Watters, 1999). Conglutinates also may resemble worms, insect larvae, or other food items (Barnhart & Roberts, 1997), or simply be fragile structures that rapidly disassociate into free glochidia. The latter probably act only to facilitate the movement of the glochidia out of the marsupia. Some mussels, such as *Lampsilis*, apparently can release either conglutinates or free glochidia, perhaps dependent on the time of year or the presence or absence of hosts. Glochidia or conglutinates may be moved to the suprabranchial chamber and expelled through the excurrent opening, but in many lampsilines, the distal portion of the marsupia rupture and conglutinates are expelled directly to the outside. Recently, "superconglutinates" were discovered in several southern species (Haag et al., 1995; Hartfield & Butler, 1997). Superconglutinates are groups of individual conglutinates formed into a single lure. The lure is played out in the water on a strand of mucus up to 2.5 m long. No Ohio River species has been found with superconglutinates.

Some species have modified the mantle into lures resembling fishes, insects, and other food items. These structures may undulate in swimming-like motions (Kraemer, 1970). Often the marsupial portion of the gills is protruded out of the shell between these flaps. When struck by a predatory fish, females snap their shells closed on the protruded marsupia, causing the marsupia to rupture and release clouds of glochidia. These attach to the would-be predator. Radically different mantle lures have been found in the same "species," such as *Lampsilis fasciola*, suggesting either the presence of sibling species, or a startling polymorphism in mantle pigmentation and morphology within single species, even in a single population. There is some evidence that mussels and glochidia can detect nearby hosts and modify their behavior to increase their chances of attracting or attaching to them (Henley & Neves, 1997). Mantle tissue is sensitive to changes in light intensity, and may react to the shadows of passing fishes (Hove & Anderson, 1997). In addition, it has been suggested that mantle tissue may release chemical attractants for hosts (Pepi & Hove, 1997).

Once shed by the female, glochidia must acquire a suitable host or die, usually within 24-48 hours. "Free" glochidia are preyed upon by numerous predators: insects, bottom-feeding fishes, flatworms, hydras, etc. Infective glochidia may travel some distance downstream in currents (Clark & Stein, 1921; Neves & Widlak, 1988). The estimated chances of a glochidium surviving to metamorphose and excyst range from 0.0001% (Jansen, 1991) to 0.000001% (Young & Williams, 1984). Although some species may compensate for this with high fecundity over many years (Bauer, 1987b), other species have been shown to develop late and then reach early senescence (Downing et al., 1993). Species having lures and conglutinates generally produce fewer glochidia, but are not able to parasitize as wide a range of hosts as those that broadcast large numbers of glochidia (Watters, 1997b). Because of the manner in which hosts acquire glochidia (lures, conglutinates, webs, etc.), it is not surprising to find that glochidia are overdispersed, that is, most hosts are either unparasitized, or carry but a few glochidia, whereas a very small number of hosts bear most of the parasite burden (Bangham, 1940, 1955; Weir, 1977; Dartnall & Walkey, 1979; Neves & Widlak, 1988). However, even

heavily infested hosts show few ill effects, with few exceptions. Recently parasitized fishes may become lethargic and secretive, but usually recover within 24 hours. Large, hooked glochidia, such as occur in *Strophitus undulatus*, may cause great agitation to hosts when attaching.

Glochidia clamp down on the host tissue, causing cells to rupture. This cellular fluid forms part of the food for the developing parasite (Arey, 1924b, 1932b; Blystad, 1924). A host wound reaction forms a capsule by the movement of host cells over the glochidium (Faussek, 1895; Arey, 1921, 1932a). During growth, the larva will resorb much of its own tissue, including the adductor muscle and much of the mantle, as well as feeding on the host (Young, 1911; Blystad, 1924). The glochidia of most mussel species, except those of the margaritiferids and the axe-head shaped glochidia of *Potamilus*, do not appreciably change size during encystment. After a certain amount of time (from days to months), depending on water temperature and mussel species, the glochidium metamorphoses into a juvenile and excysts (Schierholz, 1889; Howard & Anson, 1923). Even at the same temperature, the duration of metamorphosis varies with host species. For instance, metamorphosis of *Megalonaias nervosa* on gar took several weeks longer than metamorphosis on bass (Watters, unpubl.). Lower threshold temperatures necessary for completion of metamorphosis were identified for *Lampsilis cardium*, and undoubtedly exist for all species (Watters & O'Dee, 1997b, 1999). At temperatures below these thresholds, metamorphosis may be delayed indefinitely. The duration of metamorphosis decreases with increasing temperature, until an upper threshold is reached. At this point, glochidia excyst, fail to metamorphose, and die (Dudgeon & Morton, 1984). Barnhart and Roberts (1997) found that although higher water temperatures greatly decreased the time to metamorphosis, metamorphosis occurred on more hosts species at lower temperatures. Glochidia metamorphose into juvenile mussels. Whereas the glochidium lacks a foot and gills, and has a single adductor muscle, the juvenile has a functional foot, gill "buds", and two adductor muscles. In many species (except anodontines), the glochidial shell is white, but turns tan or brown after metamorphosis. Anodontione glochidia typically are tan. The glochidial shell is incorporated into the adult shell, and may be visible in exceptionally well-preserved specimens (Hoggarth, 1987)

Once metamorphosed, the juvenile drops from the host and burrows into the substrate (Bauer, 1986; Clarke, 1986; Buddensiek et al., 1993) or attaches to a larger object with a byssal thread. This buried juvenile stage may last several years, and has been referred to as the mesoconch (Clarke, 1986). The thread is lost in adults, but persists for a year or more in some species (i.e., *Truncilla donaciformis*). The thread is formed by a gland within the foot, and is very similar to the byssal threads of marine bivalves, such as *Mytilus*.

Potential hosts may possess one of two types of immunity to attached glochidia. Natural immunity occurs in unsuitable hosts, which have tissue responses against the glochidia (Howard, 1914a; Bauer & Vogel, 1987). Acquired immunity occurs when a suitable host has been previously parasitized, and has built up a temporary immunity. The number of exposures needed to achieve acquired immunity depends on the degree of prior

infestations and duration between them (Lefevre & Curtis, 1910; Surber, 1913; Reuling, 1919; Arey, 1924a; Bauer, 1987a). For example, for Largemouth Bass exposed to *Lampsilis cardium*, three to four exposures over 30 day intervals are required to elicit complete immunity (Watters, 1996b). Acquired immunity to one unionid species was thought to give the host immunity to others (Reuling, 1919), but this has not been substantiated. Indeed, Largemouth Bass possessing a complete immunity to *Lampsilis cardium* were successfully infected by glochidia of *Utterbackia imbecillis* (Watters, 1996b) and even its congener *Lampsilis fasciola* (Watters & O'Dee, 1997c). Although acquired immunity may be demonstrated in the laboratory, acquired immunity in wild-caught fishes has been observed only once, and its overall prevalence in wild fishes is unknown (Watters & O'Dee, 1996). In both natural and acquired immunity, encysted glochidia are killed by the host, and either sloughed off or absorbed (Arey, 1932c; Fustish & Millemann, 1978; Zale & Neves, 1982; Waller & Mitchell, 1989). Acquired immunity apparently may be lost if no subsequent reinfestation occurs within a certain time period, and the fish may become susceptible to parasitization again. However, the amount of time needed to lose acquired immunity is not precisely known.

Host specificity varies greatly among mussels. Some species, usually widespread and abundant, are able to parasitize many species of fishes, including exotics (Trdan & Hoeh, 1982; Watters & O'Dee, 1997a; Watters & O'Dee, 1998). Other mussel species, usually localized and rare, may use only a few fish species. This has been substantiated in numerous laboratory trials. These hosts typically are members within a fish family that share the same habitat as the mussel. Regardless, fishes must be present at the right time and the right place to serve as hosts. This is particularly true of migratory fishes. Because this symbiosis is obligatory, plans to conserve and manage rare and endangered mussels must include management of the host as well. It is suspected that some mussel populations are not reproducing because their hosts no longer occur with them. The hosts of the great majority of mussels have not been identified, and it is not known if hosts identified in laboratory infections actually function as hosts in the wild.

This host-parasite relationship apparently arose as a means of dispersal for the unionids. Lacking internal fertilization and great motility as adults, unionid populations would be doomed to be carried to the sea over many generations. By attaching themselves to a highly motile host, such as a fish, they are dispersed within and between drainages. Records of dispersal on the feet of waterfowl are largely apocryphal (Rees, 1965), and the idea that glochidia swim by clapping their shells, once the preferred theory, has been abandoned. Obviously, other freshwater mollusc groups are equally as successful as freshwater mussels, without resorting to parasitism for dispersal. Time and again in nature we see such juxtapositions of disparate evolutionary "solutions" to common problems. Asking why this solution arose instead of that one is probably an exercise in futility.

Effects of Impoundment

Rivers have been dammed by humans for millennia for many purposes: to run mills and

hydroelectric turbines, to irrigate otherwise inarable land, to control floods, to allow navigation of waterways, and for recreation. But impoundments are not the same as naturally occurring pools in a river. Impoundments have a different hydrology than natural pools, with different flow patterns, topographies, and temperatures. These differences often result in a change in the aquatic fauna, including mussels. For example, 15 mussel species were found in Lake Cooper, a man-made impoundment on the Mississippi River, but in adjacent Lake Pepin, a naturally-formed pool, 30 species were encountered (van der Schalie, 1938).

The loss of these mussels and their hosts is due to habitat modifications caused by impoundment. A free-flowing river has riffles, runs, pools, shoals, water-willow stands, and meanders. But impoundment dramatically reduces this habitat heterogeneity (Bates, 1962; Blalock & Sickel, 1996). The original channel remains but is buried under deeper water. However, most mussels do not occur in deep water, and those that do are often stunted (Haukioja & Hakala, 1974; Lewandowski & Stanczykowska, 1975). This channel begins to accumulate sediments, smothering most mussels and eliminating breeding areas for hosts. Ellis (1936) showed that a silt accumulation of one-quarter to one inch depth resulted in mortality approaching 90% in the mussels he tested.

If not smothered outright by accumulating sediments, mussels may be affected adversely in other ways. Reproduction may be reduced or stopped entirely, and growth may be slowed. Bates (1962) found no evidence of mussel reproduction in the channel of Kentucky Lake of the Tennessee River, even though adult mussels were present. Rivers having high levels of suspended solids result in slower mussel growth (Semenova et al., 1992). Juvenile mussels, which live buried for several years, may be killed by overlaying sediments (Bauer et al., 1980; Buddensiek et al., 1993). Silt results in the loss of light penetration, reducing algal food available to mussels, and leads to oxygen depletion. The bottom waters of the channel may become cold enough to stunt the growth of mussels (Harman, 1974; Ghent et al., 1978; Semenova et al., 1992) and interfere with reproduction (Hruska, 1992).

After impoundment, the original mussel fauna may be eliminated or greatly reduced (Holland-Bartels, 1990), or changed in favor of silt-tolerant species, such as anodontines and species of *Leptodea* and *Potamilus* (Bates, 1962; Blalock & Sickel, 1996; Clark & Gillette, 1911; Ellis, 1931; Isom, 1969; Klippel & Parmalee, 1979; Parmalee & Hughes, 1993). These often occur in the now permanently inundated floodplains. Thus, while some impoundments may contain numerous mussels, these invariably are invading soft-substrate adapted species that have replaced the original fauna.

Dams may represent physical barriers to mussel hosts. Some mussel populations may no longer be recruiting juveniles because their hosts are absent (Suloway et al., 1981; Jones, 1991; Burkhead et al., 1992). Watters (1996a) showed that dams as low as one meter in height affected host movements and restricted the range of some mussels. Tailwaters tend to accumulate mussels, which is another source of evidence that the dam is acting as a barrier.

Tailwaters are affected as well (Ligon et al., 1995). Fluctuating water levels may strand or otherwise expose mussels to extreme temperatures, resulting in mass mortalities. (Riggs & Webb, 1956; Neck & Howells, 1994). Low temperatures associated with some tailwaters may affect mussel reproduction and growth. High-volume water discharges and abrupt stoppages cause instability of substrate below dams (Miller & Payne, 1992; Nagel, 1992; Yeager, 1993). Sedimentation in tailwaters reduces fish diversity and abundance by altering necessary habitats, thereby removing necessary mussel hosts (Petts, 1984; Holland & Huston, 1985; Nelson et al., 1987). Mussels may be absent for miles below some dams due to these problems.

That impoundments are detrimental to aquatic life, and most mussels in particular, has been demonstrated by many case studies. Perhaps several dozen mussel species in North America, and numerous more freshwater snails, were driven to extinction by the affects of impoundments (Stansbery, 1973; Layzer et al., 1993; Lydeard & Mayden, 1995). Although mussel faunas change through time, with or without dams, and species become extinct as a matter of course, the interference of humanity has dramatically accelerated this process. For example, the Tennessee River's mussel diversity decreased from 100 species to 44, mainly due to impoundment (Isom, 1969). In the Fort Loudoun Reservoir alone on the Tennessee River, Isom (1971) found only four mussel species, while Ortmann (1918) reported 64 species from the same general area before impoundment. The area of the Chickamauga Reservoir of the Tennessee River supported 46 species for perhaps 2000 years prior to impoundment (Parmalee et al., 1982). After impoundment, 28 species were extirpated, and several are now extinct, all in the blink of an evolutionary eye. Similar reductions in diversity after impoundment were documented for the Cumberland River (Layzer et al., 1993; Schmidt, 1986), where the construction of the Center Hill hydroelectric dam resulted in the loss of 78% of the original mussel species. In the Little Tennessee River, only six of the original 50 mussel species at Tellico Lake remained after impoundment (Parmalee & Hughes, 1993). The mussels of other rivers have met a similar fate, including mussels of the Kaskaskia River (Suloway et al., 1981) and the Tombigbee River (Williams et al., 1992).

Mussel Indices

The OSU Mussel Database uses two indices to quantify mussels in the Ohio River mainstem:

1) Index of Mussel Potential (IMP)

This index is simply the sum of all matches between fish hosts and a given mussel species for all pools on the Ohio River mainstem. The number, therefore, is based on the number of pools in which a mussel species lives and the number of available fish hosts for that species in the pools. The higher the number the more "potential" that mussel species has to survive within the Ohio River mainstem, all other things being equal.

2) Index of Pool Potential (IPP)

This index is similar to the IMP, but matches between mussels and fish hosts are summed within a pool. The result may be used as an indicator of the "potential" of a given pool to maintain mussels. The value is driven by the diversity of both mussels and fish.

Additional details concerning these indices are included on the database CD.

Discussion

The Ohio River has been sampled for freshwater mussels since the at least the 1700's. In some instances these specimens still exist, with sufficient locality data, to be useful in reconstructing the original mussel fauna of the Ohio River. The records used here date back to 1800 in several instances, providing a lengthy record of mussels in several pools. Prior to impoundment the average depth of the Ohio River was ~ 1 ft. deep. Frontier accounts clearly depict the Ohio River as an often wadeable, meandering series of riffles, runs, and pools. As today in relatively unaltered riverine systems, we know that mussels occupied distinct river reaches – some species were most common in riffles and runs while others preferred pools and backwaters. The construction of dams eliminated the riffles and pools, presumably driving some species (and/or their hosts) to extirpation or even extinction. All of the currently extinct North American mussel species, predominately in the genus *Epioblasma*, were big river riffle/run species.

The charts presented here show a mixed effect of the dams on the mussel fauna. In pools such as Hannibal, McAlpine, and Smithland, the effects are marked. But in other pools little effect is apparent: Dashields, Greenup, and Markland, for example. Often the effect is not immediate; in some cases nearly a decade passes before declines are apparent. This is due to two causes. First, an artifact created by the timing of the next survey post dam construction – if the next survey is ten years after the dam is placed in operation, then the diversity estimate will not be updated until that time. Second, there may be a biological reason for the lag time. This may reflect the lack of recruitment in some mussel populations while their adults age and eventually die off in the pool.

Based upon historical records we know that each pool or reach supported 40-50 species of mussels; today many have less than ten. Pools now have an average of 60-80 species of fishes. Unlike mussel species, most fish species have persisted in pools for the past several decades. No fish species is considered extirpated from the Ohio River mainstem.

In nearly all cases the most dramatic declines in mussels are obviously associated with the arrival of zebra mussels in the Ohio River in 1991. Often these declines are precipitous. However, the overall diversity is usually found to be already in decline prior to zebra mussels, and this decline is often attributable to impoundment. Thus, the overall loss of mussels in each pool is rarely attributable to any one cause; rather zebra mussels seem to work on an already declining diversity caused by impoundment, loss of hosts,

and pollutants. The loss of mussels does not seem to be attributable to a loss of hosts; most pools have a wide variety of fish that could act as hosts to these mussels. While it is possible that some very host specific mussels, perhaps now extinct, may have been affected by the loss of the proper fish, this is probably the exception.

The following section presents pool-by-pool results starting with Emsworth Pool at Pittsburgh, the most upstream pool, and continuing downstream to near Cairo, IL, at the Ohio's confluence with the Mississippi River.

Emsworth

There are no historical mussel records for this pool. Only 32 species of fish have been recorded, all but one since 1988. *Pimephales notatus* has not been collected since 1958.

Dashields

The Dashields Pool has one of the longest records of mussels in the river, dating to 1800's. Records indicate that this reach once supported a thriving mussel community of perhaps 40 species, including the extinct *Epioblasma torulosa*, last seen in 1800. Recent surveys have found less than ten species. It is clear that the decline began as early as the late 1800's. The dam was not placed in operation until 1929 and no further surveys were conducted until the 1970's. At that time the Pool probably still supported over 20 species. No marked decline attributable to the dam is apparent in the data. Species richness began to decline ~1980. After briefly leveling off in the late 1980's, the fauna dramatically declined with the arrival of zebra mussels in 1991. The fauna today is largely comprised of mussels using freshwater drum or catfish as their hosts. The endangered *Cyprogenia stegaria* probably still exists in the pool. Dashields Pool has 54 fish species recorded from it. Only *Ameiurus melas* has not been found since 1958.

Montgomery

The mussel data from this pool are insufficient to draw any conclusions. Only two species occur in the database; neither is rare and both are more properly considered stream and lake species. Seventy-four fish species have been recorded, the majority of them recaptured in the past decade.

New Cumberland

The few mussel records available from this pool all date from the 1990's, after both dam construction and zebra mussel introduction have taken place. The data suggest a dramatic decline in mussel diversity. The IPP for this pool is only 8; fish host availability may be a problem here. Ninety-five fish species have been reported, all since 1968.

Pike Island

There is little information available for this pool – few surveys have been conducted although records date to 1900. Only five species have been recorded, four of which have been found in the 1990's. There are no records of extinct or endangered mussels from Pike Island Pool. The IPP for this pool is very low, 2, probably the result of inadequate data. Eighty-nine fish species have been recorded here, all since the 1970's.

Hannibal

Mussel data date from the early 1900's. The effects of both dam construction and zebra mussels are evident. The only endangered mussel recorded from the pool is *Pleurobema plenum*, last seen in 1901. Hannibal Pool has a low IPP of 8; relatively few of the known host fish are recorded from this pool. Eighty fish species occurred in this pool; six have not been seen since 1957-1959: *Ameiurus natalis, Hypophthalmichthys molitrix, Lythurus ardens, Notropis bucahnani, Noturus exilis*, and *Noturus nocturnus*.

Willow Island

Willow Island mussel data only dates to 1983, shows a dramatic decline immediately after the arrival of zebra mussels – from >20 taxa to <5. The only endangered mussel reported from the pool is *Pleurobema clava*, which has never been found living or fresh dead there. Willow Island Pool has an average IPP, 15. Willow Island has 73 fish species. Three have not been collected since the 1950's: *Catostomus commersoni, Luxilus chrysocephalus*, and *Pimephales promelas*.

Belleville

Belleville has among the best historical records of any Ohio River pool, dating back to the early 1800's. Except for a small decline in the 1880's, the diversity has remained fairly constant until the late 1970's. This may reflect the construction of the dam in the 1960's. However, a marked decline is associated with the advent of zebra mussels. Of the several endangered species recorded from the reach, only *Cyprogenia stegaria* apparently still exists here. Belleville Pool has a fairly high Index of Pool Potential (IPP): 23. Eighty-five fish species have been reported from this pool; only four species (*Ictalurus furcatus, Luxilus cornutus, Percopsis omiscomaycus, Polyodon spathula*) have not been recollected since 1958.

Racine

There is little historic mussel data available for the Racine Pool and none from prior impoundment in 1967. By the time of the first surveys in the 1970's, the mussel fauna is precipitously declining from nearly 50 taxa to ~30, although many of the species seen in the earlier surveys were weathered or subfossil shells. After leveling off in the late 1980's, the fauna was again decimated by zebra mussels. Today perhaps less than ten mussel species remain. The extinct *Epioblasma torulosa* occurred in this pool. The endangered *Cyprogenia stegaria* still exists in the Racine pool. Racine Pool has a high IPP, 23. Racine Pool has 75 species of fishes. All but two, collected in the 1950's (*Luxilus cornutus* and *Phenacobius mirabilis*), have been recently found.

Byrd

There is little information on mussels in the Byrd Pool. The diversity was already in decline when first surveyed, but has declined precipitously since the arrival of zebra mussels. The only endangered species, *Lampsilis abrupta*, was seen here in 1993. The very rare *Simpsonaias ambigua*, virtually unknown from the Ohio River mainstem, was found in 1995. The IPP for this pool is average for Ohio River pools: 19. The fish fauna

of this pool is particularly rich, with 94 recorded species. All species have been collected since 1973.

Greenup

Greenup mussel data show an alarming decline in diversity after the arrival of zebra mussels – from nearly 40 species to less than five. The endangered *Lampsilis abrupta* apparently still occurs in this reach. Greenup has a very high IPP (26), indicating that most of the necessary host fish are present in the pool. Ninety-five fish species are reported from this pool. Only one species, *Ameiurus melas*, has not been recaptured since 1959.

Meldahl

Mussel data date back to the early 1900's. Over 50 mussel species originally lived in this river reach. Surveys reveal a constant decline in mussel diversity. The effect of the Meldahl Dam was to speed up this decline; the arrival of zebra mussels has led to a severe decline in diversity. Two extinct mussels once occurred here: *Epioblasma torulosa* and *Epioblasma obliquata obliquata.* Several other endangered species also are recorded from here but none have been see in the past 50 years. Meldahl Pool has a high IPP of 24, suggesting that host fish loss is not a serious problem in this reach. Meldahl Pool has 86 fish species. Only three of these have not been captured since the 1950's: *Ameiurus natalis, Ameiurus nebulosus*, and *Notropis atherinoides*.

Markland

The Markland Pool may have more mussel data than any other Ohio River reach. Data is available form the 1800's through 2000, revealing an original mussel diversity exceeding 60 species. A marked decline in mussel diversity occurred in the 1840's. The fauna slowly declined to the early 1980's, past the construction of the dam. Another obvious decline occurred at this time, followed by yet another decline when zebra mussels arrived. Numerous rare, endangered, and extinct species once lived in this reach. With the exception of *Cyprogenia stegaria*, apparently still living here, none of these species have been seen in the past 50 years. Markland Pool has the highest IPP: 27.This pool has 94 fish species reported from it. All species have been captured since 1970.

McAlpine

Mussel data are available from 1800. The affect of dam construction on the mussel fauna is obvious. Mussel diversity has declined dramatically to ~1990, the last date for which we have data. Several rare or endangered mussels are known only as weathered or subfossil shells – *Cyprogenia stegaria, Lampsilis abrupta, Obovaria retusa, Plethobasus cicatricosus, Pleurobema clava*, and *Pleurobema plenum*. McAlpine Pool has an average IPP of 12. The pool has a relatively low diversity of fish: 44 species. Many have not been seen since the 1950's and 1960's.

Cannelton

Cannelton mussel records date to ~1900 and suggest a robust original fauna of ~40 species. The extinct *Epioblasma torulosa*, and other very rare species, were found as

subfossil material in 2000, but when they were lost from the pool is not known. Most of the fauna persisted until the construction of the dam in 1972, and then declined during the late 1970's into the 1980's. Mussel diversity plummeted after the arrival of zebra mussels. *Quadrula pustulosa* is the most abundant species in the pool today. The endangered *Cyprogenia stegaria* is uncommon in the Cannelton Pool. Cannelton Pool has an IPP of 16, average. Sixty-eight fish species are reported from Cannelton Pool. All have been collected since at least 1957.

Newburgh

Mussel data for the Newburgh Pool are not available before the dam was placed in operation. The few surveys performed since suggest a declining fauna, particularly after the arrival of zebra mussels. Several rare species, including the extinct *Epioblasma torulosa*, are known from the pool only as weathered or subfossil specimens. Newburgh Pool has an average IPP, 16. Newburgh Pool also has 76 fish species recorded. All have been collected since the late 1960's.

Myers

We have mussel data for the Myers Pool dating back to the early 1900's. Mussel diversity seems to have remained fairly constant until the advent of zebra mussels. After that point, the mussel diversity has precipitously declined. The Myers Pool has two mussel species that are usually considered more southern taxa – *Plectomerus dombeyana* and *Quadrula apiculata aspera*. This probably represents the northernmost extent of these species. Myers Pool has an average IPP, 18. Myers Pool has 76 fish species reported. Only three, *Notropis stilbius, Noturus eleutherus*, and *Noturus nocturus*, have not been collected since 1957.

Smithland

Records for the Smithland Pool date to 1800 and clearly show the impact of impoundment in 1980. The fauna has been reduced from its original 36 taxa to less than 15. This includes the extinct *Epioblasma torulosa* and several endangered species. Effects from zebra mussels are not as dramatic here as in other pools. Smithland Pool has an average IPP, 15. Eighty-nine fish species have been found here. Four species have not been collected since the 1950's: *Cycleptus elongatus, Notropis stilbius, Noturus exilis*, and *Rhinichthys oculus*.

Olmsted

Mussel data for the Olmsted Pool dates back only to the early 1980's, well after the dam was constructed in 1928-29. Diversity has declined from nearly 30 species to perhaps less than ten. Because of the paucity of records, all species are indicated as rare. *Plethobasus striatus* was found in 1987 and *Potamilus capax* in 1991; both are endangered. Olmsted Pool has a high IPP, 20. Fish data are separated into Locks 52 and 53 for this pool. Lock Pool 52 has 64 species, Lock Pool 53 has 77. Six species have not been collected since the 1950's.

Lock and Dam 53

This river segment, which is not impounded, has relatively few mussel data and few conclusions may be drawn from them. Not surprisingly, several southern species, *Arcidens confragosus* and *Quadrula apiculata aspera*, occur here. The very rare and endangered *Plethobasus striatus* was found here as late as 1982. Fish data were not available for this river reach near Cairo, IL.

Data Notes

The database is only as good as the data it contains. In a perfect world, we would know the distribution of every mussel and fish, and which fish act as hosts for which mussels. In the real world we have only incomplete data. In particular we have only partial lists for host-mussel associations. Thus the data, and the conclusions drawn from them, must be carefully examined in light of these shortcomings.

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Contents of OSU Mussel Database CD

1. Mussel-Fish Access Database
2. ArcView File
3. Excel format Pool Rankings (ohio-coe1.xls)
4. Excel format Gravid Periods (breeding.xls)
5. Excel format Mussel Species List by Pool ("poolnameX".xls)
6. Excel format Fish Species List by Pool (fishpools.xls)
7. Excel format Mussel Common Names (clamnames.xls)
8. Excel format Fish Common Names (fishnames.xls)
9. Excel format Cumulative Mussel Distributions by Pool (damplots.xls)
10. Word format (COEreport.doc)

United States Department of the Interior

FISH AND WILDLIFE SERVICE
3761 Georgetown Road
Frankfort, Kentucky 40601

February 6, 2006

Veronica Rife, PM-C
U.S. Army Corps of Engineers
Louisville District
P.O. Box 59
Louisville, Kentucky 40201-0059

Subject: FWS#06-0484; Planning Aid Letter regarding ORMSS PEIS

Dear Ms. Rife:

The U.S. Fish and Wildlife Service (Service) has prepared this Planning Aid Letter (PAL) for the Ohio River Mainstem Systems Study Programmatic Environmental Impact Statement the Corps is developing. This PAL is provided in accordance with the Fish and Wildlife Coordination Act (FWCA) (16 U.S.C. 661 et seq.) and section 7 of the Endangered Species Act (ESA) of 1973, as amended (87 Stat. 884; 16 U.S.C. 1531 et seq.).

This PAL does not constitute the report of the Secretary of the Interior as required by section 2(b) of the FWCA, nor does it constitute a biological opinion under section 7 of the ESA. This PAL provides guidance and recommendations regarding the ongoing ORMSS and development of the PEIS by the Corps.

The Corps focus of this PEIS differs from most EIS's developed in the past for proposed construction at one or a few sites. This PEIS should present economic, engineering, and environmental information to evaluate broad system investment alternatives, and it should also provide information regarding overall impacts of the program, including cumulative effects, so that the decision-makers can make a reasoned judgment of the merits of the actions at the present state of planning or development through consideration of effects of navigation improvements on environmental sustainability. As a Federal agency, the Corps has had the major role in creating and maintaining the current navigation system. The Corps role in determining how this navigation system will look into the future includes the responsibility to do everything it can to minimize its impacts to the natural resources and to create conditions in which the natural resources can be enhanced, recovered, and sustained throughout the extent of the river. We urge the Corps to include in the ORMSS PEIS a commitment to maximize the overall project benefits to federal trust resources and to provide details on how it will avoid, minimize, and/or compensate for any trust resources that are adversely impacted.

The Cumulative Effects Assessment (CEA), which the Corps is working on to include in the ORMSS PEIS, analyzes the impacts on the environment that result from implementation of the Ohio River mainstem navigation system modernization when added to other past, present, and reasonably foreseeable future actions regardless of what agency or person undertakes such other

actions. We urge the Corps to be as detailed as possible regarding this cumulative effects assessment and to include how actions completely unrelated to the proposed action have and/or will affect the natural resources.

The Service has participated with the Corps on this project for several years primarily in the capacity of the Interagency Working Group (IWG). The Service believes the IWG has been effective and can continue to provide input and guidance to the Corps on this project. We urge the Corps to continue to involve the IWG during completion of the ORMSS PEIS, and to continue its involvement as the Corps moves forward developing specific projects.

The Corps has been providing several sections or chapters of the PEIS for Service review. Many of these have been draft documents for which the Service has not seen the final version. The Service has been providing input to the Corps on these draft documents; however, it would be helpful if these sections or chapters could be reviewed in a final form before the Service prepares the FWCA Report for this project for inclusion into the final PEIS. We anticipate providing a draft FWCA to our state partners for review within the next few weeks. We also anticipate including their input into the draft FWCA we present to the Corps in the near future. The Service will continue to cooperate with the Corps regarding the ORMSS PEIS. We believe its success is crucial to providing guidance to future Corps projects on the Ohio River and how these activities may impact federal trust resources.

Thank you for the opportunity to comment on this important matter. Please contact Leroy Koch at 502-695-0468 if you have any questions regarding this letter.

Sincerely,

Virgil Lee Andrews, Jr.
Field Supervisor

cc: Corps, Huntington, WV (David Rieger)
Corps, Nashville, TN (Tom Swor)
USFWS, Marion, IL (Joyce Collins, Mike Thomas)
USFWS, Bloomington, IN (Mike Litwin, Scott Pruitt)
USFWS, Reynoldsburg, OH (Mary Knapp, Jeromy Applegate)
USFWS, Elkins, WV (Tom Chapman)
USFWS, Parkersburg, WV (Patty Morrison)
USFWS, Marion, IL (Rob Simmonds, Greg Conover)

DRAFT PROGRAMMATIC AGREEMENT
AMONG

THE U.S. ARMY CORPS OF ENGINEERS, PITTSBURGH, HUNTINGTON AND LOUISVILLE DISTRICTS,
THE ADVISORY COUNCIL ON HISTORIC PRESERVATION, AND
THE STATE HISTORIC PRESERVATION OFFICERS OF PENNSYLVANIA, OHIO, WEST VIRGINIA, KENTUCKY, INDIANA AND ILLINOIS
REGARDING
THE MODERNIZATION OF
THE OHIO RIVER NAVIGATION SYSTEM

WHEREAS, the U.S. Army Corps of Engineers, Pittsburgh, Huntington and Louisville Districts (Corps), propose to modernize the existing Ohio River Navigation System, consisting of Locks and Dams located in Pennsylvania, West Virginia, Ohio, Kentucky, Indiana and Illinois; and

WHEREAS, the Corps has determined that modernization of the Ohio River Navigation System and concomitant environmental mitigation efforts (Project) may have an effect upon properties included in or eligible for inclusion in the National Register of Historic Places (National Register) and has consulted with the Advisory Council on Historic Preservation (Council) and the State Historic Preservation Officers of Pennsylvania, West Virginia, Ohio, Kentucky, Indiana and Illinois (SHPOs) pursuant to Section 800.14 of the regulations (36 CFR Part 800) implementing Section 106 of the National Historic Preservation Act (NHPA, 16 U.S.C. 470f), and Section 110(f) of the same Act (16 U.S.C. 470h-2(f)); and,

WHEREAS, pursuant to 36 CFR 800.2, the Corps conducted a series of public and agency meetings between July 10, 2001 and August 7, 2001, throughout the project area, designed to give all interested parties an opportunity to comment on the overall Project; and

WHEREAS, the Project shall be defined as those activities undertaken by the Corps that are required to modernize Locks and Dams, including all construction staging areas, all flowage easement acquisitions, all disposal sites, all publicly owned shoreside facilities relocated at Federal expense, and all environmental mitigation; and as defined excludes activities undertaken by the private sector as a consequence of the Project, which may affect historic

properties, the Section 106 obligations of which will be addressed separately through Department of the Army permitting authority under Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. 403), and Section 404 of the Clean Water Act (33 U.S.C. 1344);

WHEREAS, the Corps, in order to facilitate the assessment of Project effects, has prepared a National Register of Historic Places-level contextual report, which has been coordinated through the SHPOs; and

WHEREAS, the Corps, has conducted a historic architectural survey of all extant and former Corps lock and dam facilities along the Ohio River, through consultation with the SHPOs; and has completed the appropriate state inventory forms for agency review. The final report will be completed and distributed by the Winter of 2005/06; and

NOW, THEREFORE, the Corps, the Council and the SHPOs agree that the Project shall be administered in accordance with the following stipulations to satisfy the Corps' Section 106 responsibility for all individual undertakings of the Project.

Stipulations

The Corps shall ensure that the following measures are carried out:

I. Completion of Historic Property Surveys

A. The Corps shall ensure that historic property surveys will be performed in the Project's area of potential effects as defined in the Council's regulations at 36 CFR Section 800.16(d). The objective of these surveys is to identify both recorded and unrecorded potentially historic properties within the area of potential effects that may be affected by the Project either directly or indirectly, and determine whether they meet the criteria for inclusion to the National Register of Historic Places as specified in the Department of Interior's regulation at 36 CFR Part 60.4.

B. Historic property surveys will be performed in accordance with the Secretary of the Interior's Standards and Guidelines for Archaeology and Historic Preservation

and other applicable professional standards as described below.

II. Identification and Treatment of Archaeological Properties

A. Identification and Evaluation

1. Phase I archaeological survey will be performed on all lands that will be disturbed by the Project. The surveys will be conducted in a manner consistent with the Secretary of the Interior's Standards and Guidelines for Identification (48 FR 44720-23) and take into account the National Park Service publication The Archaeological Survey: Methods and Uses (1978), and specific state guidelines.

2. All surveys shall be conducted in consultation with the SHPO who has jurisdiction where the surveys will take place. All reports will meet the standards of the appropriate SHPO and shall be submitted to that SHPO for review and comment.

3. Where the Phase I archaeological survey results in the identification of a historic property, but yields insufficient information to properly determine the National Register of Historic Places eligibility for that property, a Phase II archaeological testing program will be developed and coordinated with the appropriate SHPO. The goal of the Phase II testing program will be to glean sufficient information about the property to make an eligibility determination.

4. The Corps, in consultation with the appropriate SHPO and following the Secretary of Interior's Standards for Evaluation, shall apply the National Register Criteria to properties that may be affected by this project. If the Corps and the appropriate SHPO agree that a property is eligible under the criteria, the property shall be considered eligible for the National Register for purposes of this Agreement. If the Corps and the appropriate SHPO agree that the criteria are not met, the property shall be considered not eligible for the National Register for purposes of this Agreement. If there is no agreement between the Corps and the appropriate SHPO on National Register eligibility, or if the Council so requests, prior to the start of any work at the site the Corps shall submit

the property for a formal determination of eligibility from the Keeper of the National Register, National Park Service, whose determination shall be final.

5. For those archaeological properties which the Corps and appropriate SHPO agree are not eligible for the National Register, no further archaeological investigations will be required, and the proposed project may proceed in those areas. If the survey results in the identification of properties that the Corps and the appropriate SHPO determine to be eligible for the National Register, such properties shall be treated in accordance with Stipulation II(B) below.

6. NAGPRA

a. Federal Fee Title Lands.

i. In the event that Native American human remains, associated and unassociated funerary objects, sacred objects, and/or objects of cultural patrimony are encountered during any phase of the project on tribal land, or federal fee title lands, or on lands in which the federal real property interests are virtually equal to fee title, the burial discovery is subject to NAGPRA, Section 3 (Public Law 101-601-Nov.16, 1990) and the Department of the Interior's NAGPRA Regulations (43 CFR Part 10).

ii. The Corps and appropriate federally recognized tribal entity shall notify the appropriate SHPO and the Council of the outcome of tribal consultation and disposition.

iii. The SHPOs and the Council shall be consulted to amend the provisions of this agreement if the NAGPRA tribal consultation and subsequent disposition impairs the Corps' ability to execute this agreement.

b. Non Fee Title Lands

In the event that Native American human remains, associated and unassociated funerary objects, sacred objects, and/or objects of cultural patrimony are encountered during any phase of the project on state, local, or private lands, the burial discovery is subject to state burial laws.

B. Determination of Effect and Treatment

The Corps, in consultation with the appropriate SHPO and the Council, shall determine the effect the Project will have on each listed or eligible archaeological properties and develop a treatment plan for any archaeological properties that will be adversely affected by the Project.

a. Preservation In Place

i. Wherever feasible, preservation in place shall be the preferred treatment. Such properties shall be avoided either through project design changes, use of temporary fencing or barricades, or other measures to protect sites.

ii. The Corps, in consultation with the appropriate SHPO, shall develop and implement a plan for long term protection of archaeological sites avoided and preserved in situ on lands affected by the Project.

iii. The Preservation plan will be submitted to the appropriate SHPO and the Council for 60 days (from receipt of documentation) for review and approval. The parties shall consult to resolve any objections to the preservation plan as proposed prior to implementation. If no response is received from the SHPO or the Council after 60 days (from receipt of documentation), the plan shall be implemented as submitted.

b. Archaeological Data Recovery

i. For those eligible archaeological sites that the Corps, the appropriate SHPO, and the Council agree cannot be avoided, a data recovery plan for the retrieval of significant archaeological information will be developed and implemented.

ii. A data recovery plan that addresses substantive research questions will be developed in consultation with the appropriate SHPO for the recovery of relevant archaeological data. The plan shall be consistent with the Secretary of the Interior's Standards and Guidelines for Archaeological Documentation (48 FR 44734-37) and take into account the Council's publication, Treatment of Archaeological Properties and the appropriate

state publication. It shall specify, at a minimum, the following:

(a). The property, properties, or portions of properties where data recovery is to be carried out;

(b). The research questions to be addressed through the data recovery, with an explanation of their relevance and importance;

(c). The methods to be used, with an explanation of their relevance to the research questions;

(d). The appropriate treatments and methodologies, and consultation procedures to be employed if any materials specific to NAGPRA are encountered;

(e). A proposed schedule for the submission of progress reports to the SHPO.

iii. The data recovery plan shall be submitted to the appropriate SHPO and the Council for 60 days (from receipt of documentation) for review and approval. The parties shall consult to resolve any objections to the data recovery plan as proposed. The data recovery plan shall then be implemented. If no response is received from the SHPO or the Council after 60 days (from receipt of documentation), the plan shall be implemented as submitted.

iv. The data recovery plan will be carried out by or under the direct supervision of an archaeologist(s) who meets, at minimum, the Secretary of the Interior's Professional Qualifications Standards (48 FR 44738-9).

v. An adequate program of site security to protect the site from vandalism during data recovery will be developed in consultation with the appropriate SHPO and then implemented.

vi. Curation and Dissemination of Information:

(a). In consultation with the appropriate SHPO, all materials and records resulting from the survey, evaluation, and data recovery conducted for the Project will be curated in accordance with 36 CFR Part 79. The Corps will curate all materials in a repository meeting federal standards within the appropriate state. All

material and records recovered from non-Federally owned land shall be maintained in accordance with 36 CFR Part 79 until their analysis is complete and, if necessary, are returned to their owners.

(b). The Corps shall ensure that all final archaeological reports resulting from actions pursuant to this Agreement will be provided to the SHPOs, the Council, and upon request, to other interested parties. All such reports will be responsive to contemporary standards and to the Department of the Interior's Format Standards for Final Reports of Data Recovery Programs (42 FR 5377-79). Precise locational data will be withheld from the general public or provided under a separate appendix to the reports if the Corps and the appropriate SHPO agree to the data's release.

III. Identification and Treatment of Above-Ground Historic Properties

A. Identification and Evaluation

1. The Corps, in consultation with the appropriate SHPO, shall ensure that a historical architectural survey will be conducted in those areas affected by the Project but not previously investigated as part of the Ohio River Navigation System. This survey will be conducted by a qualified architectural historian who meets, at minimum, the standards set forth in the Secretary of the Interior's Professional Qualifications Standards (48 FR 44738-9).

2. All of the areas surveyed will be clearly identified and the rationale used in eliminating areas from the survey (e.g. because either no above ground facilities will be located in view of extant structures, no flowage easements will be acquired, etc.), will be described. The criteria to be used in eliminating survey areas will be established in consultation with the appropriate SHPOs.

3. Particular attention will be given in the survey to the visual integrity (setting) of identified historic properties, and how the setting may be affected by view of the navigation structures or other Project-related activities.

4. The Corps will ensure that the architectural survey meets the standards of the appropriate SHPO, and is consistent with the recommended approaches in the Secretary

of the Interior's Standards and Guidelines for Identification (48 FR 44720-3) and the Council's and National Park Service's publication Identification of Historic Properties (1988).

5. As necessary to supplement the review of above-ground historic property documentation, the appropriate SHPO may conduct an inspection of National Register-listed or eligible properties. The appropriate SHPO shall report each determination, along with the rationale for their decision.

6. The Corps, in consultation with the appropriate SHPO and following the Secretary of Interior's Standards for Evaluation, shall apply the National Register Criteria to properties that may be affected by this Project. If the Corps and the appropriate SHPO agree that a property is eligible under the criteria, the property shall be considered eligible for the National Register for purposes of this agreement. If the Corps and the appropriate SHPO agree that the criteria are not met, the property shall be considered not eligible for the National Register for purposes of this Agreement. If the Corps and the appropriate SHPO do not agree on eligibility, or if the Council so requests, the Corps shall obtain a determination from the Keeper of the National Register, whose determination shall be final.

B. Determination of Effect and Treatment

1. The Corps, in consultation with the appropriate SHPO and the Council, shall determine the effect the Project will have on each Register-listed or eligible historic building, structure, landscape, or archaeological site.

2. The Corps, in consultation with the appropriate SHPO and the Council, shall develop proper treatments for Register-listed and eligible historic buildings, structures, landscapes, and archaeological sites that will be adversely affected by the Project.

a. The preferred alternative is avoidance of effects to historic properties. If, in consultation with the appropriate SHPO and the Council, all parties agree this is not feasible, the Corps will develop and implement plans to minimize or reduce the effect.

b. The Corps shall prepare Memoranda of Agreement (MOA) that detail mitigation plans that are developed in consultation with the appropriate SHPO and the Council. Plans will also be made available for review and comment to interested parties, affected landowners, and appropriate local interest groups. Any such comments shall be made available to the appropriate SHPO and the Council and shall be taken into account by the parties to this agreement. The appropriate SHPO and Council shall have 60 days from receipt of adequate information in which to review and comment on the MOA. If the appropriate SHPO or the Council fails to respond within 60 days, that party shall be deemed to have consented to the matter proposed. The MOA shall contain dispute resolution language that will guide consultation if there is a disagreement over adequacy, appropriateness, or extent of a mitigation plan. If the disagreement cannot be resolved, it will be handled in accordance with Stipulation V. G. below.

IV. Public Outreach And Education

The Corps, on a case-by-case basis, will consult with the appropriate SHPO regarding the appropriateness and level of effort for a public outreach and education program. This consultation will occur through the development of MOAs for individual undertakings within the overall study reach.

V. Review of this Programmatic Agreement

A. The terms of this Agreement shall remain in effect through the completion of the project in the year 2060 unless changes have been negotiated and approved as specified below.

B. The signatories to this Agreement shall consult every five years through the life of the project to review implementation of the terms of this Agreement. Prior to the review, a report shall be provided to the signatories detailing how obligations pursuant to this Agreement have been carried out. The report shall also be made available for public inspections (information regarding the location of archaeological sites shall be withheld). If revisions to this Agreement are needed, the signatories to this Agreement will amend the agreement in accordance with Stipulation V.E. below.

C. The Council and the SHPOs may monitor activities carried out pursuant to this Agreement, and the Council will review such activities if so requested. The Corps shall cooperate with the Council and the SHPOs in carrying out their respective monitoring and review responsibilities.

D. This Agreement will be circulated for public and agency review as part of an Environmental Impact Statement (EIS) being prepared for the project under the National Environmental Policy Act (NEPA) and Section 106 of the NHPA. In consultation with the SHPOs, the Corps shall develop additional means to inform the interested public of the existence of this Agreement, and about how the obligations under the terms of the Agreement are to be met. Copies of this Agreement and relevant documentation prepared under it shall be made available for public inspection (information regarding the locations of archaeological sites shall be withheld). Any comments received from the public under this Agreement shall be taken into account.

E. This Agreement may be amended by a consensus of the parties to this Agreement. Any party to this Agreement may request that it be amended, whereupon the parties will consult in accordance with 36 CFR Section 800.14 to consider such amendment. Amendments shall be in writing and signed by all parties to this Agreement.

F. Any party to this Agreement may terminate it by providing thirty days notice to the other parties, provided that the parties will consult during the period prior to termination to seek agreement on amendments or other actions that would avoid termination. In the event of termination, the Corps will comply with 36 CFR Subpart B, Sections 800.3 through 800.8 with regard to individual undertakings covered by this Agreement.

G. Should any party to this Agreement submit an objection in writing to the Corps regarding any action taken or proposed with respect to implementation of this Agreement, the Corps shall consult with the objecting party and attempt to resolve the objection. If the Corps determines that the objection cannot be resolved, the further comments of the Council shall be requested in accordance with 36 CFR Part 800.7 with reference to the

subject of the dispute. Responsibility to carry out all other actions under this Agreement that are not the subject of the dispute will remain unchanged.

H. Execution and implementation of this Programmatic Agreement evidences that the Corps has satisfied its Section 106 responsibilities for all individual undertakings of the Project, and that the Corps has afforded the Council an opportunity to comment on the undertaking and its effects on historic properties.

U.S. ARMY CORPS OF ENGINEERS, HUNTINGTON DISTRICT

By:_____
Date:_____
William E. Bulen, Colonel, Corps of Engineers,
District Engineer

U.S. ARMY CORPS OF ENGINEERS, LOUISVILLE DISTRICT

By:_____
Date:_____
Raymond G. Midkiff, Colonel, Corps of Engineers,
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U.S. ARMY CORPS OF ENGINEERS, PITTSBURGH DISTRICT

By:_____
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ADVISORY COUNCIL ON HISTORIC PRESERVATION

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OHIO RIVER MAIN STEM CONTEXT STUDY

HISTORIC CONTEXTUAL STUDY

September 2001

Prepared for

U.S. Army Corps of Engineers
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INTRODUCTION

The Ohio River Main Stem Navigation System consists of 20 lock and dam structures and the Louisville and Portland Canal. These structures stand along the 981-mile length of the Ohio River through or along six states from Pittsburgh, Pennsylvania, to Cario, Illinois. The Louisville and Portland Canal opened in 1830 and, in bypassing the Falls of the Ohio, established the Ohio River as an important route to the West. Subsequent improvements have enhanced the system to allow reliable and cost-efficient transportation of raw materials, basic manufactured products, and consumer goods.

This study, undertaken under terms of contract number DACW59-98-D-0009 for the Pittsburgh District of the U.S. Army Corps of Engineers, seeks to document the national and regional historical context of this engineering achievement. While the historical importance of the system is obvious on its face, this study collected, organized, and analyzed historical data to assist the Corps of Engineers in complying with regulations requiring that federal agencies identify, manage, and take into account the effects of their undertakings on significant cultural resources, including Sections 106 and 110 of the National Historic Preservation Act, as amended.

A multiple property National Register of Historic Places Nomination will be prepared from the information presented herein to assist the Corps of Engineers in evaluating the significance and National Register eligibility of the individual structures and features of the system. Accordingly, the Criteria of Evaluation of the National Register of Historic Places provided an important framework for this study. The Criteria of Evaluation state:

> The quality of significance in American history, architecture, archaeology, engineering, and culture is present in districts, sites, buildings, structures, and objects that possess integrity of location, design, setting, materials, workmanship, feeling and association, and:
>
> A. that are associated with events that have made a significant contribution to the broad patterns of our history; or
>
> B. that are associated with the lives of persons significant in our past; or
>
> C. that embody the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic value, or that represent a significant and distinguishable entity whose components may lack individual distinction; or
>
> D. that have yielded, or may be likely to yield, information important in prehistory or history (36 CFR 60.6).

This study was undertaken to support National Register eligibility evaluation under Criteria A, B, and C.

In designing this study, five areas of research were identified as research foci. They are summarized in the following sets of questions included in the Task Order for this study:

A. In what ways does the navigation system reflect social, economic, and political change? Which national or regional engineers, politicians, and commercial/industrial

leaders are closely associated with the system or individual structures? In what ways?

B. Did the locks and dams make a significant contribution to regional industries, their patterns of development and productivity? To what extent were these industries dependent upon the navigation system? To what extent is the regional and national significance of these industries linked to the presence of the navigation system?

C. In what ways did the presence of navigation structures and pools influence population development, the growth of cities and villages, and agriculture? Consider, in particular, the development of Pittsburgh, Huntington, Louisville, and Cincinnati.

D. Did the navigation system play a significant role in the war efforts of World War I, World War II, and the Korean War? If so, explain how.

E. Discuss the technological significance of the Ohio River lock and dam system and the navigation industry that evolved with it. What new technologies (including new building materials and construction techniques) were introduced in this system? Explain the development of these technologies. How did these technologies affect later river improvements elsewhere in the United States or in other nations? Were innovations in ship building technology attributed to the system?

In researching these topics, it became clear that while all were interrelated, several were so closely related that it was not really possible to meaningfully separate them. Accordingly, the three essays presented here address in turn: 1) the engineering of the system, 2) political factors and military influences, and 3) community and economic development. Each of these essays builds upon the rich literature on the history of the Ohio River and offers new insights from extensive primary source research completed as part of this study. We hope that a better future can be built from this better understanding of the past.

CHAPTER I

HISTORIC ENGINEERING EVALUATION

by

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CHAPTER I

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DEVELOPMENT OF THE OHIO RIVER NAVIGATION SYSTEM

Early Improvements

Before the beginning of navigation improvements, snags, rocks and gravel and sandbars obstructed the Ohio River, rendering navigation difficult and hazardous. Channel depths varied considerably from a minimum of one foot between Pittsburgh and Cincinnati to two feet between Cincinnati and the river mouth (Jones 1929:2).

Legislative efforts aimed at funding the removal of Ohio River obstructions began in 1803. In that year, the Kentucky Legislature passed a resolution inviting the State of Ohio to join it in providing funds to pay for the removal of obstructions to navigation. Citing financial considerations, the Ohio Legislature declined to participate. In 1806, in response to a second request, the State of Ohio appointed commissioners "for the purpose of exploring the rapids of the River Ohio." During the following decade, states launched additional multi-state efforts to improve the Ohio River culminating in a four-state report that mapped all sandbars and proposed two routes for a canal at the falls of the Ohio (Kreisle 1971:47).

Early on, the improvement of Ohio River navigation became a stated national priority. Secretary of the Treasury Albert Gallatin wrote of the necessity of improving inland navigation in a report on roads and canals submitted to the U.S. Senate in 1808. In this report, he advocated the construction of a canal to provide passage around the Falls of the Ohio (Gallatin 1808:27).

Waterway historian Leland Johnson attributes much of the initial push for Ohio River navigation improvements to the inter-city rivalry between Pittsburgh and Wheeling and the droughts of 1818-1819. Long a leading trade center because of its location at the head of the Ohio River, Pittsburgh faced losing this role when the National Road bypassed it to the south and met the Ohio River at Wheeling. Extended droughts in 1818 and 1819 rendered the navigation of the Upper Ohio very difficult. Reports indicated that more than $3 million worth of commodities rotted on Pittsburgh's wharves while awaiting shipment. Pittsburgh's civic leaders solicited donations for the purpose of removing rocks in the channel that hindered navigation.

At the same time a joint state commission appointed to survey the river and plan its improvement for navigation passed through Pittsburgh enroute to Louisville. During their survey of the drought-plagued river they saw more than 30 boats that had run aground in the channel. The commissioners recommended that each state bordering the river appropriate $10,000 to remove the boulders, snags, rock ledges, and gravel bars that obstructed navigation (Johnson 1991:186).

Only Pennsylvania responded to the call. The state's legislature appropriated $15,000 in 1821. Laborers blasted rocks, cleared snags and boulders, and with teams of oxen pulling plows and scrapers, dredged channels through gravel bars. Returning each dry season until funds were exhausted, the laborers maintained a low water channel deep enough to permit small boats to travel the Ohio River as far as Wheeling (Johnson 1991:186).

Federal involvement in the improvement of the Ohio River began on April 14, 1820 when Congress appropriated $5,000 for the "survey of the Ohio and Mississippi Rivers from the Rapids at Louisville, to the Balize for the purpose of facilitating and ascertaining the most practicable mode of improving the navigation of those rivers" (Bernard and Totten 1822:2). In October 1821,

Brigadier General Simon Bernard and Brevet Lieutenant Colonel Joseph G. Totten, accompanied by two other officers, left Louisville to begin the survey (Reuss 1982:x).

In 1822, the Board of Engineers presented Bernard and Totten's completed report to President James Monroe. The surveyors found two major types of navigational hazards on the Ohio River, the Falls of the Ohio at Louisville and shoals of gravel and sand. In describing the former, the authors wrote:

> Amongst the great number of obstacles which the Ohio River presents to navigation, the falls at Louisville are certainly the first in importance, for, if boats, coming from above and bound for the Mississippi, do not arrive at Louisville at the period when the superior and inferior waters are on a level, or nearly so, from floods, they are either obliged to pass the falls at great risk, or they are detained and transport it in vessels constructed below the falls. All the country, therefore, connected with the Ohio, above Louisville, is deeply interested in opening a passage round the falls, which shall be practicable at all seasons when the river is so (Bernard and Totten 1822:13).

The surveyors identified 21 shoals of sand or gravel that posed hindrances to navigation. The bars allowed sufficient water passage for keel and flat bottom boats, but prevented navigation by steamboats, with their greater drafts, for five or six months every year (Bernard and Totten 1822: 15).

To address these hazards, the surveyors proposed the construction of dikes which, by narrowing the channel, would cause it to be deepened. The authors briefly described dike construction in the report:

> These dykes [dikes] across the river are ordinarily formed by rows of piles, driven with force into the bed, and strongly wattled together, the spaced between the rows being filled with such rough stones, or large paving stones, as the neighborhood can supply (Bernard and Totten 1822:20).

Bernard and Totten suggested that such dikes initially be used on bars that had less than three feet of water flowing over them. The board expressed caution concerning the efficacy of this remedy:

> It is certain that, by the dykes and narrow passages, the water may be deepened at any required point; but it is to be feared that in some places at least the localities may be such that the very materials thus carried off by the rapid waters may be deposited when they become comparatively quiescent in such a way as very soon to form a new bar below (Bernard and Totten 1822:21).

As their response to the report, the United States Congress passed legislation on May 24, 1824 appropriating $75,000 for clearing sand and debris from the Ohio River and the Mississippi below St. Louis, generally in accordance with the Bernard-Totten plan. An additional $40,000 was provided for pier improvements on the two rivers (Shallat 1994:127). To direct the initial experimental research on wing dams called for in the report, the Army's Chief Engineer dispatched Major Stephen H. Long to the Ohio. In 1824-1825, he supervised construction of the first navigation dam on the river near Henderson, Kentucky. In this experiment, he drove parallel rows of wooden pilings in the riverbed, filled the space between them with stone, and experimented with differing lengths, widths, and heights until he developed an efficient design.

The resultant 402 yard long wing dam extended from one bank toward the channel at a 45 degree angle downstream to confine river flow at low-water stages and to erode the obstructing gravel bar. Sediment gathered against the dam and anchored it to the riverbed. The total cost of construction was $3,378.93.

The second major project funded by the appropriation was snag removal. To secure a machine capable of removing snags, the Chief Engineer offered engineers and scientists a $1,000 prize for the best design. The winning design, submitted by Captain John W. Bruce of Vanceburg, Kentucky, consisted of a twin-hulled boat with a windlass between the two hulls. Attaching a cable from the windlass to a snag, workers turned the windlass to raise the snag from the river for disposal (Johnson 1991:188).

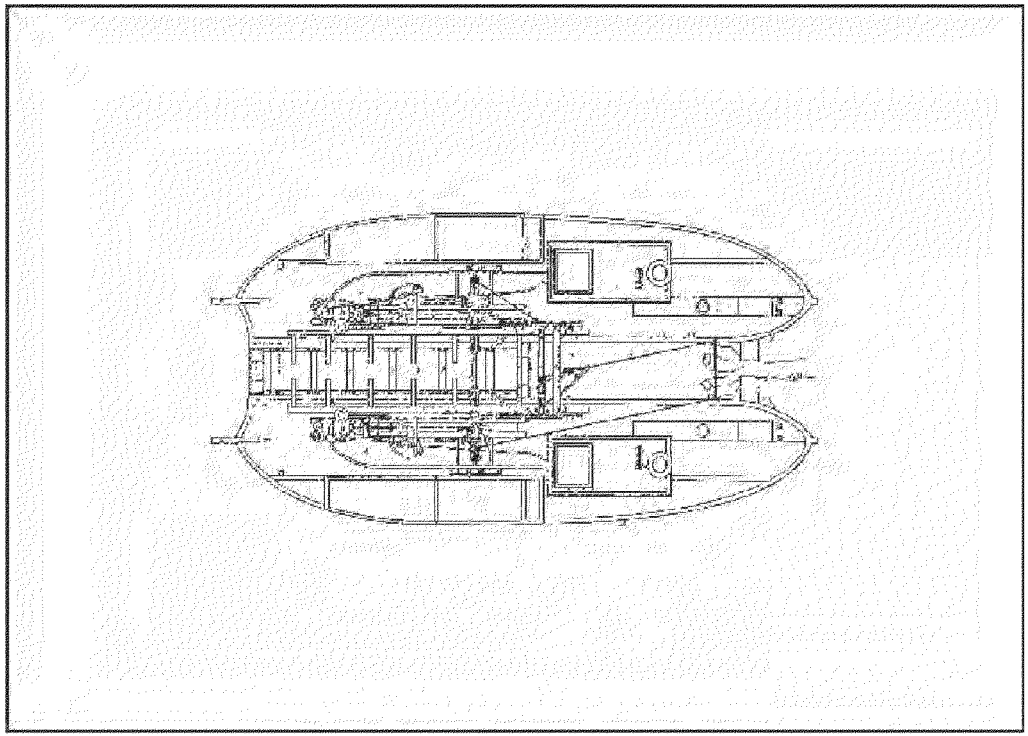
Bruce began work at Pittsburgh in 1824 and continued downriver in 1825. However, he made no attempt to clear the Ohio for steamboats. Finding a loophole in the contract, a phrase that referred to trees that blocked navigation "at the lowest stage of the water," Bruce removed only the logs in the low-water channel during the driest months. His contract was suspended. As a subsequent report indicated, "however well this invention recommended itself in theory, it was, in practice, found to be utterly useless" (U.S. House 1830:3).

After the failure of this snagboat, Henry M. Shreve, described as an "old and practical navigator of the western waters," was appointed to continue snag removal. His efforts were funded by a $30,000 Congressional appropriation on March 3, 1827. On March 3, 1827, Congress appropriated $30,000 for continued snag removal. In November 1827, Henry Shreve reported that he had succeeded in removing the obstructions off the bars and island chutes for a distance of 300 miles upstream from the mouth of the river (U.S. House 1828:3).

Shreve advocated the construction of a steamboat for improved snag removal, noting that it could operate at any stage of river when snags could be seen. With the permission of the U.S. Department of War, he was authorized to apply a portion of the Mississippi River funding to the construction of this boat. The craft, dubbed *Heliopolis*, a double-hulled steamboat joined by a platform with a windlass geared to the engine (Figure 1-1). Shreve described the boat in his patent application:

> It consists of a double or twin boat...connected by two tiers of beams: the upper tier running from the midships or centers of the boats to the stern..., decked over on the tops of the upper beams; the lower tier running from midships towards the stern, about half the distance of the upper tier, and sealed, sheathed, or planked, under said lower tier of beams, and secured by diagonal timbers...running on the top of the lower tier of beams, framed on to each beam, and secured by a bolt passing through the beam. The front or forward end of the two sets of beams are connected by a strong bulkhead,...fixed in an inclined position, and sheathed with sheet iron, about one-fourth of an inch thick, the lower side of the bulkhead being thirty inches forward of the upper side, forming an inclined plane, by which the end of a snag is conducted on deck by the impetus of the boat, when the snag comes in contact with said bulkhead (U.S. House 1843:3, 9).

Figure 1-1. Plan of Henry Shreve's snag boat (from Shallat 1994).



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Despite these initial expenditures, Ohio River crafts continued to be lost as a result of striking snags. A number of Kentucky residents sent a petition to Congress requesting further appropriations to clear additional snags:

> ...all are compelled to send the effects of their labor down the Ohio and Mississippi rivers to market, in the various craft that usually navigate those streams; that these great and navigable rivers are in many places, obstructed with trees, stumps, and roots of trees...whereby the navigation of them is retarded and rendered very hazardous; and by them, many of the various craft on the rivers, with valuable cargoes, are annually lost, to the great injury and distress of the adventurers, who frequently embark on board of them, with the effects of their year's labor, and often their all, as well as endangering the lives of the men sailing said craft (U.S. House 1828:1-2).

The petitioners noted that during the previous few years 19 steamboats had been totally lost together with cargoes, and the lives of crew and passengers. In addition, other steamboats suffered damage estimated at $125,000. An average of 30 flat boats were also lost every year (U.S. House 1828:2).

After Long's first successful experiment with the use of wing dams, the Corps of Engineers planned additional structures to eliminate obstructions. In 1831, Congress appropriated $150,000 for the construction of additional dikes on the Ohio. Dikes were begun at Scuffletown and Sisters Islands in 1831, and at French and Cumberland Islands in 1832. All of these locations were downriver from Owensboro, Kentucky. The wing dams generally assured a minimum channel depth of three feet. As a result of the success of these first structures, a large number of wing dikes and back channel dams were built between Pittsburgh and Cincinnati (USACE-ORD 1979:11; Office of History 1998:42; Johnson 1975:80).

These structures were built almost entirely of large rough stones deposited in the stream at the site of the works with little attempt at systematic arrangement. By 1840, the system had begun to deteriorate with some dams breaking and others causing sand to be deposited around them. By the latter part of the nineteenth century, these rough stone dams and dikes were replaced by more substantial timber structures, ballasted with stone or furnace slag and roughly paved on their upper surfaces with stone (Arras 1908:244; Kreisle 1971:77).

The Louisville and Portland Canal

The earliest major navigational improvements on the Ohio River occurred at the Falls of the Ohio at the present city of Louisville, Kentucky. The falls, actually a series of rapids formed by ledges of limestone rock, extend two miles along the river, dropping 26 feet at low water. Three main passages extended through the rapids. Indiana Chute, the longest, had a relatively uniform slope along its three-mile length. During low water, it was subdivided by the center rock into two with the better channel being sixteen feet wide and sixteen inches draft at low water. Middle Chute, a passage between Goose Island and Rock Island, extended approximately 2 1/16 miles and dropped 22 feet within the last 500 yards. Kentucky Chute branched off Middle Chute at Rock Island and dropped 26 feet within the last 185 yards. Middle and Kentucky chutes were navigable to descending traffic only during times of high water. Indiana Chute was navigable for the careful boatsman for ten months in the average year, but upstream traffic was limited to approximately two months (Bernard and Totten 1822:13-14). Boat traffic through the falls was restricted to craft

up to 14 feet wide, because the Indiana Chute had two projecting rocks that narrowed the channel (ACS 1988:20).

Because of the dangers inherent in shooting these rapids, most boats stopped above the falls. Goods and passengers were transported two and one-half miles overland to Shippingport, Kentucky, below the falls. The break in navigation was an important factor in the early growth of Louisville (Kreisle 1971:29).

A canal around the falls was initially proposed as early as 1804. In that year, the Legislature of Kentucky incorporated the Ohio Canal Company. Competing proposals were developed by proponents of a canal on the Kentucky side of the river and those proposing a canal on the Indiana side. Kentucky and Indiana each chartered a canal company in 1805. The act incorporating the Ohio Canal Company specified that construction had to begin within three years and be completed by January 1, 1812. A lottery was authorized to permit the company to raise as much as $15,000 for canal construction. No construction took place.

In 1818, the two states again chartered rival companies. The Kentucky enterprise, known as the Kentucky-Ohio Canal Company failed to begin construction. The Indiana company began preliminary excavations, damming Cone Creek and cutting a new channel for it along the line of the canal, but a financial panic doomed this enterprise (Walker 1932:21-23; Trescott 1958:687; ACS 1988:20).

The Board of Engineers on the Ohio and Mississippi Rivers prepared a report on the need for the canal in 1821. Noting that "amongst the great number of obstacles which the Ohio river presents to navigation, the falls at Louisville are certainly the first in importance," the authors noted that several canal proposals had been developed. One proposal was to leave the river a half mile below Bear Grass Creek and rejoin it just below Shippingport. A second proposed canal would have left the river between Corn Island and the Kentucky shore and have its outlet between Shippingport and Rock Island, a total of two miles. A third canal was proposed for the Indiana side, leaving the river at Jeffersonville and following two ravines to an outlet at Clarksville (Monroe 1823).

Construction of the canal was successfully undertaken by a private stock company, the Louisville and Portland Canal Company, chartered in Kentucky in 1825 with an authorized capitalization of $600,000 divided into $100 shares (Walker 1932:25). Canvass White served as canal engineer (Roberts 1857:26). From the beginning, nearly 40 percent of the stock was owned by the United States government, a total of 2,335 shares, costing $233,500 (Humphreys 1868:5). The federal government's share gradually increased. By 1855, the government had acquired effective control of the enterprise.

The Louisville and Portland Canal bypassed the falls (Plate 1-1). It was opened in 1830. Upon completion, the canal was 1.9 miles long and 64 feet wide in the clear. It included three lift locks in series at the foot of the canal (Plate 1-2). Each lock had a lift of slightly over eight feet, chamber length between miters of 198 feet and usable length of 170 feet, and a width of 50 feet (Plate 1-3). This canal, whose total construction cost was slightly more than $1 million, was the first successfully major improvement to the great central river system of the United States (Oakes 1914:564; Trescott 1958:694).

Plate 1-1. Plan of the Louisville & Portland Canal and vicinity. From Filson Club collection, Louisville.

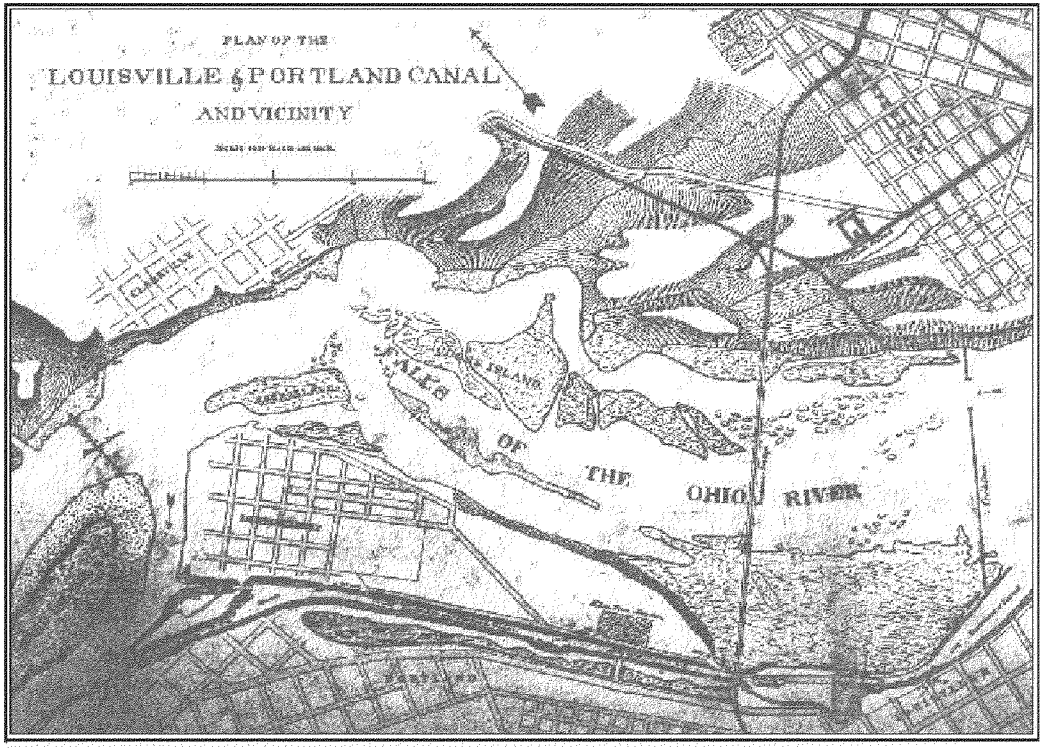

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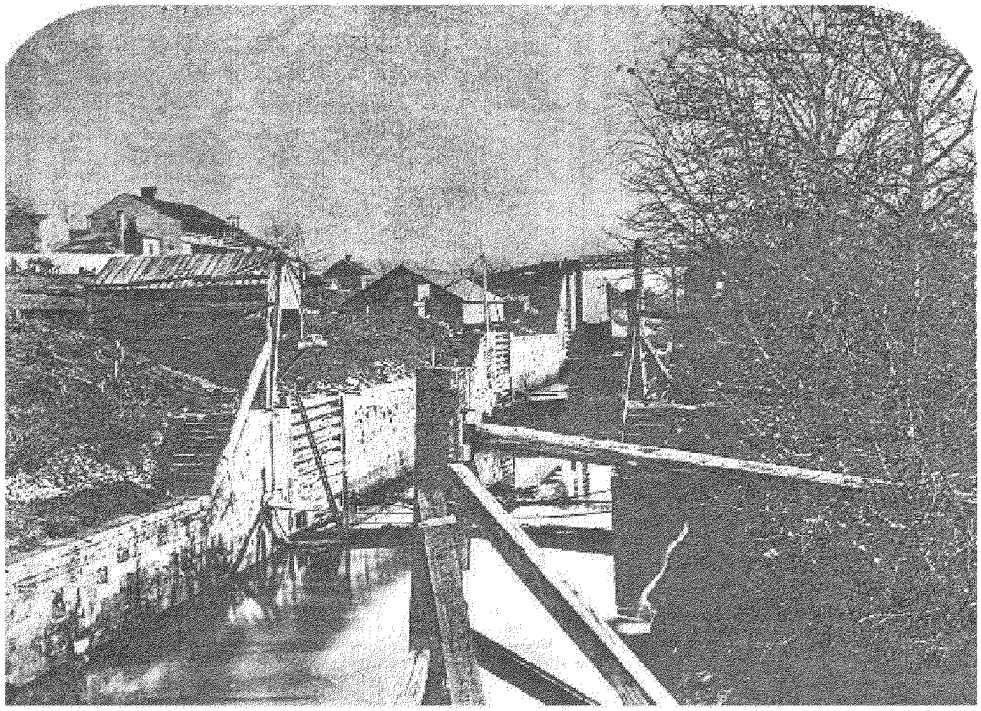
Plate 1-2. Louisville and Portland Canal. Original three stage lock (E. Klauber n.d.). From Filson Club collection, Louisville.



Flatboats passed through the canal beginning in early December 1830, and the first steamboat, *Uncas*, locked through on December 21st. During the first twelve months of operation, 406 steamboats and 375 flatboats, with an aggregate tonnage of 76,323 tons traversed the canal (Vance 1908:140).

Business was slow during the first few years of canal operation, in part because the canal was not fully completed until 1833. The company discovered that the initial toll rate of twenty cents per ton could not provide the profits permitted in the charter, so the toll was raised to forty cents in 1832 and sixty cents in 1837. By 1839, annual toll revenues had reached $180,000 and annual traffic grew to 1,666 steamboats and 578 keelboats with an aggregate tonnage of over 300,000. High tolls were a source of continuing concern to boatsmen and shippers, and petitions were regularly presented to Congress urging that the government buy out the remaining private stockholders (Trescott 1958:695; Walker 1932:27).

The lock chambers were built for the river vessels of the 1820s and accommodated a maximum hull dimension of 183 feet long by 49 ½ foot beam. In the 1840s, many new boats were too large to pass through the canal, while others suffered delays and risked damage due to the narrowness and shallowness of the waterway (Trescott 1958:699). By 1853, more than 40 percent of the steamboats plying the Ohio were too large to pass through the canal.

In 1843, Congress authorized a survey of the best method to improve navigation of the Falls of the Ohio. This survey was completed by Captain Thomas Cram and Assistant Engineers Allan Campbell and Henry Clay Long. The engineers recommended that the United States purchase the canal, enlarge it, and construct a second canal on the Indiana bank to allow two-way traffic. At the same time, other engineers advocated the construction of a dam and lock on the Ohio River below the falls to submerge them (Johnson 1975:100) calling the existing canal "the greatest obstacle to and impediment in the way of navigation between Cincinnati and the mouth of the Ohio" (U.S. Senate 1855:7).

The engineer board recommended construction of a single lift-lock of 80 foot width equipped with three gates. These gates would permit the length of the chamber to be 220, 320 or 420 feet long depending on gate configuration. The lock was to be filled and emptied by side culverts. The canal itself was proposed to be 200 feet wide to permit craft to pass one another and have a depth to permit a maximum draft of 11 feet (U.S. Senate 1855:8-9). This proposal was not approved by Congress (Johnson 1975:100).

In 1857, the Louisville and Portland Canal Company paid for a survey by Colonel Stephen H. Long. He proposed the construction of a larger lock with dimensions adequate for the largest Ohio River steamboat (Johnson 1975:100).

In 1859, hydraulic engineer Theodore R. Scowden outlined proposed improvements to the canal in a letter to the chairman of the United States House Committee on Railroads and Canals. His plans consisted of widening the canal from 64 to 100 feet, lining both sides with 17-foot high stone walls, fixing the lowest stage of canal water at six feet over the miter sill, replacing an abrupt turn in the original canal with a shallower curve, and constructing a timber and stone crib at the head of the canal to prevent boats entering it from being swept down the falls. The new locks were proposed to be 1,500 feet downstream from the old locks and connected by a 2,600 foot long branch canal (Kreisle 1971:89-90).

The following year, Congress passed a joint resolution authorizing the company directors to construct a branch canal provided that the credit of the United States not be used to fund it. Scowden was hired to prepare detailed plans for the improvements. The enlargement was begun in 1860 and stopped in 1866 after $1,825,403 had been expended (Weitzel 1868:5; Plates 1-4 and 1-5). Two years later, Congress passed a joint resolution that authorized and directed the Secretary of War:

> To cause surveys, with plans and estimates of cost, to be made by an officer of engineers for a ship canal around the falls of the Ohio, on the Indiana side thereof, of suitable location and dimensions for military, naval, and commercial purposes; and also to cause said officer to estimate the expense of completing the Louisville and Portland canal, on the Kentucky side of said falls, according to the plan on which the canal company is now progressing with said work... (Humphreys 1868:2).

After receipt of the report from Brevet Major General Godfrey Weitzel of the United States Army, Congress voted to continue with improvements to the existing canal rather than building a new canal on the Indiana side.

In his study of the Louisville and Portland Canal, Major J.C. Oakes described the improvements:

> The work was completed practically as designed by Mr. Scowden and provided: a depth of 6 feet in the canal by means of excavation and a guiding dike and cross dam at the head of the canal....; a width of canal 86 ½ feet between vertical walls 15 to 17 feet high; two locks in series, each 372 feet between quoins or 348 feet available length by 80 feet width... (Oakes 1914:565).

Both locks were equipped with wooden mitering gates. The lock chambers were filled and emptied through butterfly valve controlled openings in the gates (Oakes 1914:568).

The most substantial modifications to Scowden's plans for the canal occurred at the dam located at the head of the falls. As early as 1868, General Godfrey Weitzel of the Corps of Engineers recommended the construction of a dike and cross dam to raise the lower water depth in the canal to 6 feet, and by 1879, the structures had been completed. These structures were built of timber cribs (Oakes 1914:572). Completion of these structures had been delayed by a series of delays including shortages of funds, high water levels, and an October 1875 collision of the barge *Citizen* with the cofferdam (USACE-ChE 1876:747-748).

The new locks were opened to traffic on February 26, 1872 (Plate 1-6) as reported in the *Louisville Courier and Journal:*

> When the locks were completed they were the largest locks in the world, 80 feet in width and 350 feet long with a lift of 26 feet. The stone for the locks and bridges was all cut at a sand quarry one hundred and twenty miles down the river from full-sized diagrams furnished by Mr. Scowden. Neither mallet nor chisel was ever used on the works and all the face stone on the works were set to their places by the instruments of the engineer (as cited in Kreisle 1971:94).

Plate 1-3. Louisville and Portland Canal. Original canal walls (E. Klauber n.d.). From Filson Club collection, Louisville.

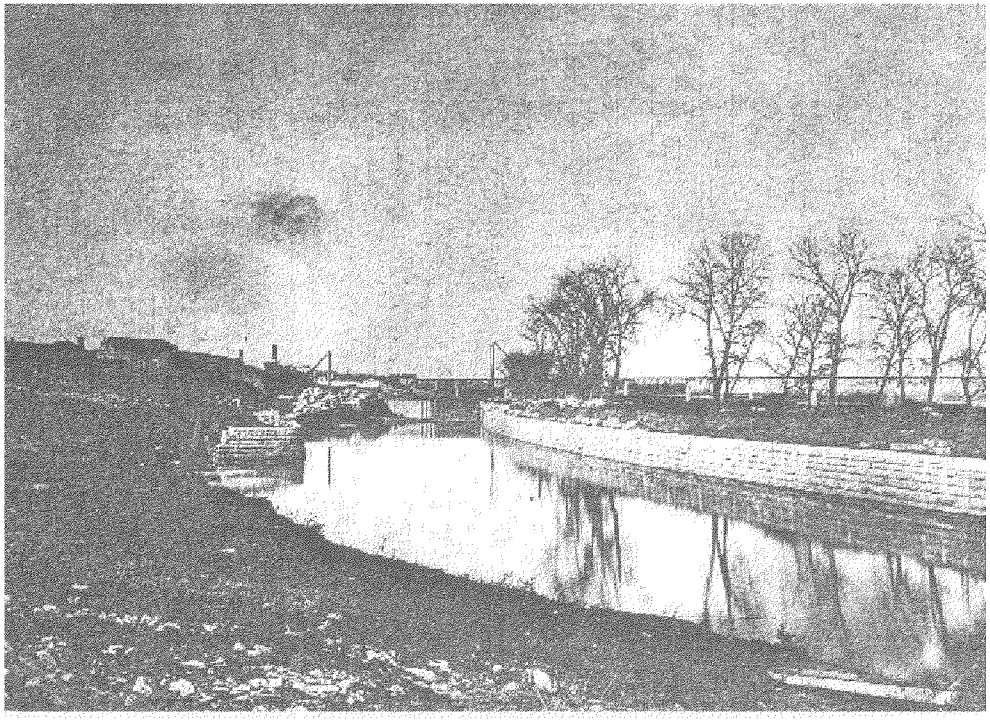


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Plate 1-4. Louisville and Portland Canal. View of new side walls and head of new locks, looking southwest. From Filson Club collection, Louisville.

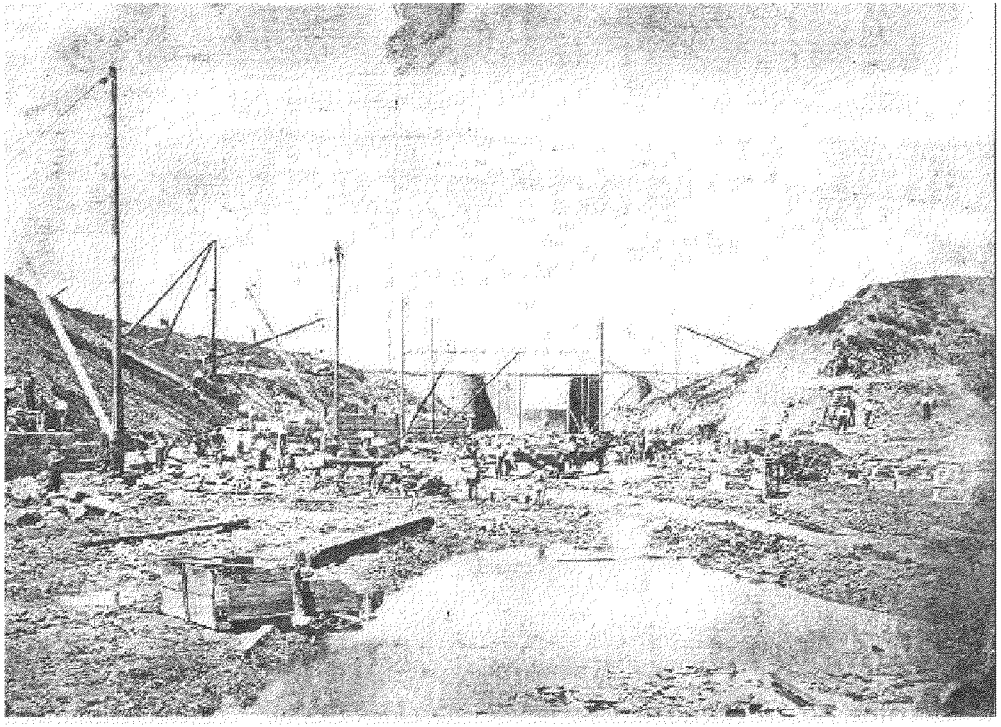

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Plate 1-5. Louisville and Portland Canal. New locks under construction, looking northeast (E. Klauber n.d.). From Filson Club collection, Louisville.

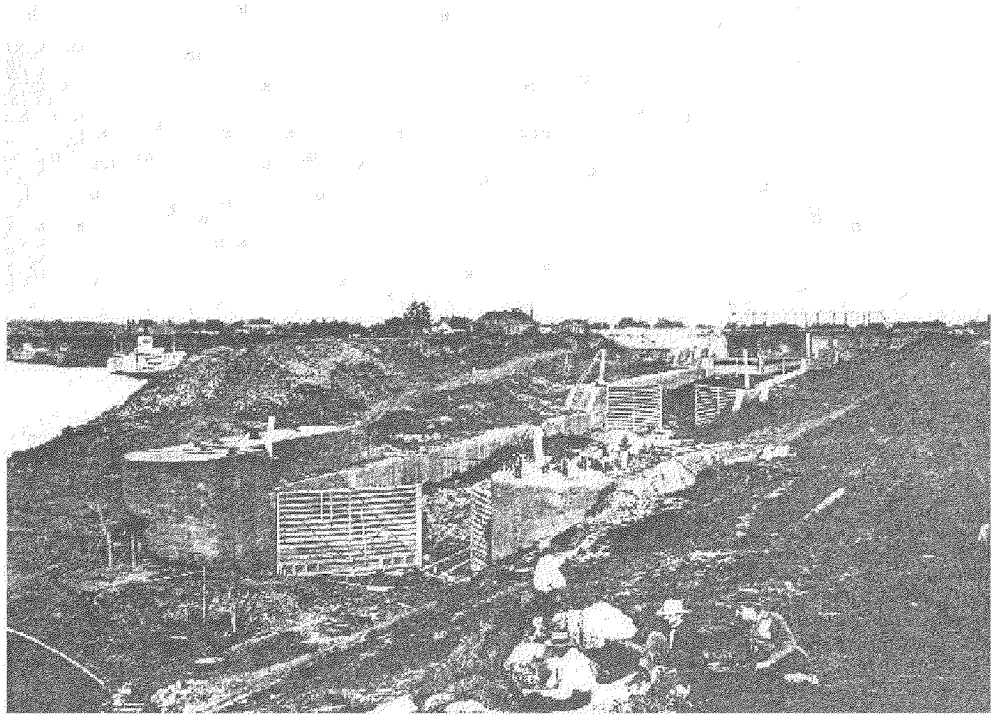

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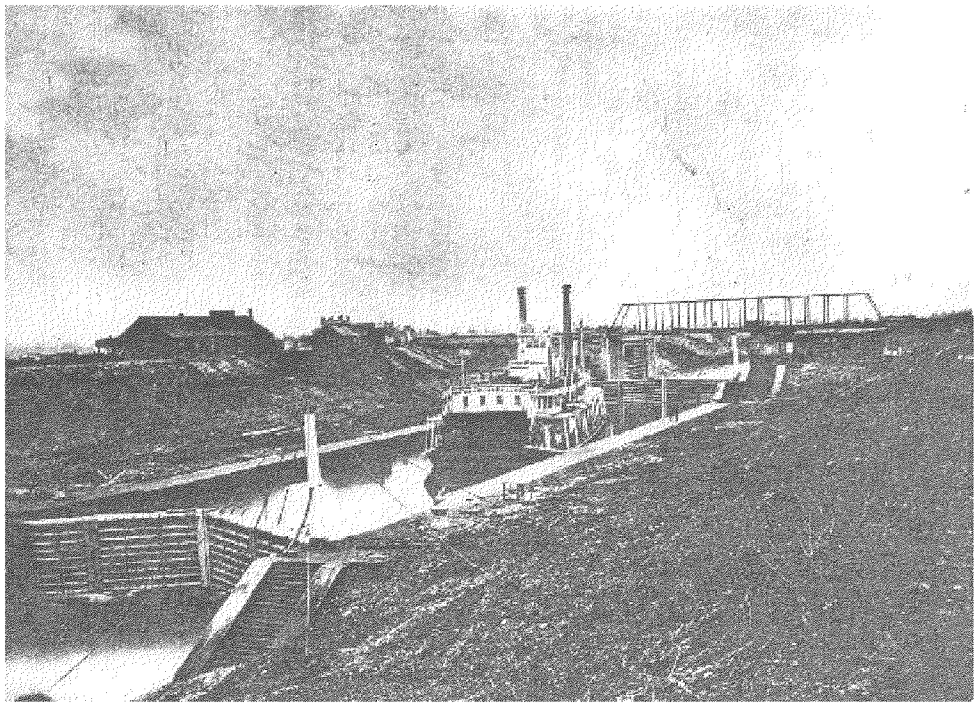
Plate 1-6. Louisville and Portland Canal. Completed new locks, looking northeast (E. Klauber n.d.). From Filson Club collection, Louisville.



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Captain Alexander Mackenzie reported on the condition of the new locks in December 1875:

> With exception of the guard-gates all parts of the new locks are in a serviceable condition. The coping of the walls is of soft stone, and has been injured in several places. The water has found its way under the miter-sills, washing out the concrete, thereby causing some of the stones to settle, but they will probably remain secure for several years. In time new sills, built of harder stone, and sunk to the solid rock, will be necessary.
>
> The lift-gates are moved with difficulty on account of their great weight and the sediment continually being deposited in front of them. No plans have yet been perfected for moving these gates by steam or water power; and the trial of horse-power has not been made (USACE-ChE 1876:757).

During the fiscal year ended June 30, 1876, a total of 982 steamboats passed through the canal, as well as 526 model barges, 1,623 square barges, and 102 small boats. Toll receipts for the year amounted to $76,669.14 (USACE-ChE 1876:753).

In 1881, the Corps of Engineers completed a timber crib dam at Louisville. This dam raised the canal pool by about three feet. From 1881 to 1901, 135,630 boats carrying cargo weighing over 37 million tons locked through the Louisville and Portland Canal. The average annual traffic was 6,780 boats carrying over 1.8 million of cargo. About 75 percent of this tonnage was coal. Lesser amounts of lumber, steel and iron products, sugar and molasses, salt and agricultural produce were also carried. Congestion proved a major problem. For example on July 6, 1902, towboats pushing 461 barges arrived at the canal. The last of these barges were not cleared until July 17th. In 1909, a movable weir dam was built to provide a minimum channel depth of nine feet from Louisville to Madison, Indiana (USAED-L 1995). This dam consisted of eleven sections of Boulé gates, Chanoine wickets, and masonry weirs (Johnson 1975:175).

Further improvements, beginning in 1913, were undertaken as part of the larger scheme of Ohio River improvements and will be discussed later in the report.

Additional River Improvement Projects and Proposals

Because Shreve's snagboats were too large to pass through the Louisville and Portland Canal, in 1835, the Corps of Engineers removed the Upper Ohio from Shreve's jurisdiction. Captain John Sanders of the U.S. Army Corps of Engineers was appointed as superintendent of the Upper Ohio project. The project consisted of three different but related types of activities: removing snags and similar obstructions, blasting away rocks to clear channels, and constructing stone riprap dikes to concentrate water flow over bars and scour away accumulated sand and gravel deposits (Johnson 1975:74). Sanders built smaller snagboats to clear the Upper Ohio along with dredges to cut through gravel bars. Shreve strove to achieve a minimum channel depth of 36 inches on the Lower Ohio, while Sanders attempted to open a channel at least 30 inches deep at low water on the Upper Ohio (Johnson1991:190).

Between 1826 and 1838, regular appropriations were made for Ohio River improvements. In 1830, work began on removal of rocks at Grand Chain. During the Van Buren administration, appropriations were terminated and existing projects were suspended. No funds were appropriated between July 1838 and August 1842. During the years of suspension, 136

steamboats sank on the Ohio River, an estimated loss of a million dollars annually (Johnson 1991:190).

When President John Tyler signed the River and Harbor Act of 1842, snag clearance resumed on the Ohio River. Captain Sanders resumed work. The Corps replaced Henry Shreve with Captain John Russell who put Shreve's snagboats to work and built more to clear the Lower Ohio and other rivers. Snag clearance lasted only three years until President James K. Polk took office and vetoed waterways appropriations on constitutional grounds (Johnson 1991:191).

Between 1845 and 1866, only two additional appropriations were made, the larger amounting to $95,000. Channel clearance began again in 1852 when President Millard Fillmore approved a new River and Harbor Act. Using funds from this appropriation, Colonel Long and Captain Russell built new snagboats and a dredge, began renewed snag clearance, and repaired wing dams. Long requested an additional $600,000 to finish channel clearance projects citing the 124 lives lost in 85 steamboat wrecks in 1854. Both the Franklin Pierce and James Buchanan administrations refused to appropriate the requested funds (Johnson 1991:191).

New appropriations for Ohio River navigation improvements began in 1866. The Chief of Engineers sent William Milnor Roberts, U.S. Civil Engineer, to Pittsburgh and General Godfrey Weitzel to Louisville to resume the work. Roberts secured workboats, cleared snags, and rebuilt wing dams, and Weitzel oversaw the enlargement of the Louisville and Portland Canal (Johnson 1991:191). Between 1825 and 1866, river improvements included construction of 111 wing and training dikes and 47 dams in back channels (Johnson 1975:86, 93).

Following the end of the Civil War, Corps officers became increasingly skeptical about the efficacy of the wing dams. Brevet Major General Gouveneur K. Warren wrote in 1867:

> I do not believe the country will ever stand such a heavy continuous outlay as the wing-dam system of the Ohio has caused, and I believe that the extravagant and useless expenditure there, in the palmy days of western river improvements between 1830 and 1844, did more than anything else to bring the whole subject into disrepute (Office of History 1998:42).

While the method of improving the navigable channel of the river by dikes and cut-off dams generally proved successful in maintaining a navigable depth of three feet, engineers recognized that such measures were inadequate to provide for the accommodation of coal fleets and other deeper draft vessels (Taft 1908:10).

By the mid-nineteenth century, more ambitious schemes began to be developed to insure adequate water depth on the Ohio River. One proposal envisioned using Lake Erie as a limitless source of water supply for the upper Ohio River. Charles Ellet, Jr., a noted civil engineer, proposed a series of reservoirs for collecting water during wet times to release into the Ohio during dry periods. Such a scheme was initially proposed for employment in England in a c. 1800 essay by the noted English civil engineer Thomas Telford (Belknap 1871:25). W. Milnor Roberts described Ellet's plan in a report to Major General A.A. Humphreys, Chief of Engineers:

> His plan contemplated no work upon the river itself; the idea being to accumulate large quantities of water in reservoirs upon the headwaters, or on the main streams above the head of the Ohio, to be drawn off and allowed to flow when needed to maintain the proper depth in the main river (Belknap 1871:4).

This scheme was elaborated upon by engineer Ellwood Morris in an article in an 1857 issue of the *Journal of the Franklin Institute* (Morris 1857). In 1855, General Herman Haupt proposed construction of a series of canals or channels, 200 to 300 feet wide and a succession of open dams six to ten feet in height, which would connect each pool on the upper Ohio. This project would have included 400 miles of dikes and 100 low dams (Roberts 1857:25). Almost 25 years later, Haupt revisited his original plan and proposed a 100 foot wide channel which might incorporate a system of floating lock gates (Haupt 1880).

A scheme supported by rivermen and developed by government surveyor Alonzo Livermore, included a combination of dams and open chutes through the dams. These chutes were arranged to retard the flow and lessen the velocity of water from the upper to the lower pool without interfering with the free passage of boats through the chutes. For a chute of 100 feet or less in width, the natural low water flow of the river was deemed sufficient without reliance on artificial reservoirs (Belknap 1871:5).

A final proposal called for a slackwater system, a series of dams and locks similar to that under construction on the Monongahela River in Pennsylvania. In August 1866, W. Milnor Roberts, who had served as engineer for the Monongahela Navigation Company between 1837 and 1840, was appointed by General A. A. Humphreys, Chief of Engineers, as superintending engineer of the Ohio River. After studying existing improvements, Roberts reported that the 47 back channel dams and 111 dikes had shown some success but the maximum depth over shoals in low water was 2 ½ feet, insufficient for the growing commercial traffic on the river (Mueller 1952:179).

In the fall of 1866, Roberts organized a new survey of the entire river to map all its pools, ripples, shoals, island and track the river slope. Following receipt of the survey, Roberts prepared a detailed report titled *Practical Views on the Proposed Improvement of the Ohio River.*

In this report, he alluded to the needs of the new coal towboats and noted that:

> A constant, reliable navigation, which should never be less than five feet at extreme low-water periods, which could usually be six feet or more, and which should afford, in times of freshets, a navigation as good as we have now in similar freshets, is the great desideratum (Belknap 1871:6).

Roberts concluded that the most efficient means of radical improvement of the river was by the construction of locks and dams providing slackwater pools with the dams navigable at times of high water. He estimated that the entire river would require about 66 locks and dams, averaging about six feet lift each. The average length of the dam on the Upper Ohio would be 1,300 feet, while on the Lower Ohio, the length would be 2,200 feet. Roberts estimated the total cost of these improvements to be about 23.7 million dollars (Belknap 1871:8, 11).

In 1870, Major William E. Merrill succeeded Roberts in charge of Ohio River improvements. After reviewing all the proposals for navigation improvements, Merrill concurred that the slackwater system was the most efficient way to insure river navigation. He dismissed the proposal to divert water from Lake Erie noting that the Ohio does not descend to the level of the lake until it reaches Parkersburg, West Virginia. Haupt's plan was viewed as too costly and requiring too much maintenance. The scheme for large reservoirs would require six reservoirs, each 25 miles long with dams 100 feet high. Merrill argued that there were not six such sites available in the Ohio Valley. He concluded that low dams would inundate little bottomland, the

engineering involved was well understood, and the dams could establish harbors for riverside cities (Johnson 1991:192).

In 1872, a board of engineer officers reported to the Chief of Engineers on options for movable hydraulic gates and dams on the Ohio. This report engendered substantial discussion including several proposals for movable dams by Pittsburgh engineer Felix R. Brunot in an article in the *Journal of the Franklin Institute* (Brunot 1874). Merrill recommended the construction of 13 locks and movable dams with Chanoine wickets, one of the dam types studied, between Pittsburgh and Wheeling. In 1875, Merrill expressed his opinion that the locks and dam system should be extended throughout the entire river (Taft 1908:10).

Representatives of river interests criticized Merrill's decision in favor of a slackwater system. Coal shippers and towboatsmen argued that dams would obstruct channels and require time-consuming breaking of tows to enter each of the locks. The difficulty posed by breaking tows was described in an 1874 report:

> Coal-fleets are so large and ponderous that they require a wide river for maneuvering; and besides, the barges must be bound together in every direction in the firmest possible manner by cables and screw-clamps. It is very tedious and difficult to make up a coal-fleet and somewhat hazardous; and it is almost indispensable when the boats are once firmly connected they should remain so until the whole fleet is landed at its destination. For this reason the passage of a lock after the fleet has started is most objectionable, and would cause insupportable delay and danger (Belknap 1874:3).

These critics also argued that the proposed improvements would raise flood heights, create stagnant slackwater pools, and eventually lead to the silting of river channels. Pittsburgh's rivermen organized a torchlight parade to protest Merrill's plan (Robinson 1983:25).

In a response to the opposition, Merrill wrote:

> The truth is, that if the Ohio River were provided with a perpetual 6-ft. navigation, there would be no need for the huge fleets that can only run during a few months in the year, and at other times are tied to the banks. The traffic in coal would become regular and constant. I am far from desiring to do anything that will injure the coal trade, and my record will show that I have worked faithfully to improve the river, and especially its upper portion, so that coal tows might run with more ease and safety; but I recognize the fact that the shipment of coal is not the only nor even the chief commerce on the Ohio River, that, however valuable in its effect on other industries, the total annual value of the coal that descends the Ohio is but $6,000,000, as compared with a general river commerce of about $200,000,000 (as cited in Anonymous 1905).

Support for the canalization proposal grew when a drought hit the Pittsburgh area. In May 1871, the river fell below boating stage not to rise again until the following winter. Barges laden with coal waited above Monongahela River dams for an Ohio River rise to permit them to descend to Cincinnati, Louisville and other ports, cities that faced fuel shortages. Because coal barges could not leave the Monongahela to travel up the Allegheny River to Pittsburgh's north sides, wagons hauled coal across downtown causing traffic jams and damaging roads. A *Pittsburgh Daily Gazette* editor supported the construction of a dam on the Ohio to allow a more dependable water

supply: "Let us no longer depend on the rain from Heaven for conducting our chief employment" (Johnson 1991:193).

Proponents of the slackwater system still had to address the issue of how to conserve the upper pool yet permit navigation over the dam at high river flow times. To remedy this problem, means to keep the chute closed during low water had to be developed.

To placate opponents, Merrill began investigating movable dams that could be lowered during high water to pass tows through without locking. In 1872, Major Merrill and Major Godfrey Weitzel were appointed to study hydraulic gates for possible use in the slackwater system dams. This charge led to a comprehensive study of all existing types of chutes, weirs, and movable dams, including structures in use in Belgium, France, Russia, Germany, and India.

During the course of this study, Major Merrill learned that the French Corps of Engineers was building movable dams that could be lowered to the river bottom at high river stages, allowing navigation over the dam. Major General Craighill, William R. Hutton, and Addison Scott traveled to France to inspect examples of the 124 movable dams the French engineers had in operation (Johnson 1977:83). The results of this investigation were presented in two reports issued by the Secretary of War in 1874 and 1875 (Belknap 1874, 1875).

Their French counterparts noted that the movable dams used on French rivers had evolved from a dam constructed on Pennsylvania's Lehigh River by Josiah White of the Lehigh Navigation Company in 1818. This dam, called a "beartrap" had been used to create artificial rises on the Lehigh to permit navigation. The beartrap was constructed of two overlapping leaves, fitted tightly in a chute formed by two guidewalls. The leaves of the trap rested in a recess in the sill of the chute. When water pressure was shut off, the leaves were lowered by gravity, opening the chute (Johnson 1977:83).

French engineers built beartraps at Neuville au Pont on the Marne River in 1840. They improved the technology by constructing buoyant leaves to assist in the raising operation. This design proved unfeasible because the current passing through the gate was too strong for ascending navigation. Subsequent French experiments and modifications led to the movable dams that American Army engineers studied on the French rivers in the 1870s.

The Americans were particularly impressed by the movable dams in use on the Seine River near Paris. This type of dam was invented in 1852 by Jacques Chanoine, Chief Engineer of the French Corps. Similar dams were also in use on the Yonne, Marne, Meuse, and Moselle rivers (USACE-Pittsburgh n.d.:15). The Chanoine dam is described in Leland Johnson's study of the Huntington District, U.S. Army Corps of Engineers:

> Chanoine dams consisted of a masonry foundation level with the riverbottom, to which long boards known as wickets were hinged. When the wickets were down, lying flat on the foundation, boats passed over them through an open channel called a navigable pass. When the river began to drop, threatening to stop navigation, men at the dam dropped a grapple into the river to catch the handle at the top of each wicket and pull it up. As each wicket was raised, a prop attached to its backside slid up a slot in the foundation and when the wicket was released the prop held it in a near vertical position. Wickets were raised one by one until a row of them, resembling a line of ironing boards on end, closed the channel and backed up water to form a slackwater pool. While the river was low, boats

> traveled the slackwater pools and were moved from pool to pool through locks. When the river began to rise, the wickets were dropped simultaneously by a tripping bar operated from the lockwall, which pushed the wickets' props to the side and allowed them to drop harmlessly to the foundation, again opening the channel for river traffic (Johnson 1977:84).

Merrill recommended that a series of movable dams with Chanoine wickets be used for the canalization of the Ohio River. These dams would address the desire of the coal interests for open-channel navigation, while at the same time providing a series of navigation pools connected by locks for use at low water periods. To accommodate the large tows on the Ohio, he developed plans for 110 by 600 foot locks, the largest locks proposed to that time (Robinson 1983:26).

Merrill proposed construction of the first experimental movable dam and lock at Davis Island, five miles below Pittsburgh.

Davis Island Lock and Dam

Critics continued to protest the proposed closing of the river to open navigation but supporters of canalization also voiced their opinions. Proponents included the Ohio River Commission and the Grange. The former, whose members represented the six states through which the river flows, argued that the interests of inland navigation had been shortchanged by Congress. Appropriations had been made, instead, to benefit coastal navigation and railroads. They urged Congress to fund a comprehensive survey of the river and construction of the Davis Island Lock and Dam (Ohio River Commission 1872). The Grange, an organization of farmers, sought cheaper transportation for agricultural products by improving the position of waterways in competing with railroads (Robinson 1983:26).

During 1873 and 1874, the U.S. Senate Committee on Transportation Routes held hearings concerning Ohio River canalization. At the conclusion of the hearings, the committee reported that waterways represented the "cheapest line of transport" and recommended "improvement of the Ohio River in such a manner as to secure from Pittsburgh to Cairo a depth of 6 feet of water at all seasons" (as cited in Robinson 1983:26).

General James K. Moorhead, former United States Congressman, president of the Ohio River Commission, the Pittsburgh Chamber of Commerce, and the Monongahela Navigation Company organized a lobbying effort on behalf of immediate authorization and funding of a lock and dam at Davis Island. After being told that no funds would be available due to the ongoing economic depression, the Pittsburgh delegation went before the House Committee on Commerce in a last ditch effort to obtain funding for construction. One of the members of the delegation, John H. Ricketson, later reported General Moorhead's speech to the committee:

> Finally General Moorhead arose, and I can see him now as he stood there, still in the vigor of his powers, and in all the magnificence of his presence. Said he: "Gentlemen, I am now only an old horse turned out to grass, but for ten years I represented my district on the floor of yonder hall, and I sat perhaps in the seat now occupied by one of you. In my time an emergency arose every now and then like the one that brings me before you today, and to meet it, we had to go out of the usual order of things. We want $100,000 for the Davis Island Dam, and we want it at once. If we don't get it, not only Pittsburgh interests, but those of the Government will suffer. Now, I want you to do for me just as I would do for you

> were our situations reversed. I want you to make a unanimous recommendation in favor of this appropriation, and we will pass it by a joint resolution of the Senate and House. Where there is a will there is a way" (as cited in Johnson 1985:44).

As he requested, the Committee voted unanimously to allocate $100,000 of a $300,000 Ohio River appropriation for commencement of construction at Davis Island. On March 3, 1875, the United States Congress enacted the Rivers and Harbors Act with the $100,000 Davis Island appropriation included (Johnson 1985:44-45).

Despite the availability of funds, construction was delayed because of the necessity of the Pennsylvania Legislature to grant the federal government jurisdiction over riparian land. Coal interests lobbied against this transfer, but in 1877, the required special legislation was enacted. Construction began at Davis Island in 1878 but was not finished until 1885 due to intermittent funding and the project's innovative design (Robinson 1983:26-27). Lieut. Frederick A. Mahan, US Army Corps of Engineers was in local charge (Anonymous 1905). The total cost of the project was $910,000. Davis Island was officially dedicated on October 7, 1885 in a ceremony attended by 50,000 spectators (Johnson 1977:93). By 1895, a total of over 2.8 million tons of freight passed through the lock annually (Carr 1999:4).

Upon its completion, the 1,223 foot dam, with its Chanoine wicket navigable pass of 559 feet, was the longest in the world. The project's 110 by 600 foot lock was also un-exceeded (Plate 1-7; Figure 1-2). This lock employed rolling gates (Figure 1-3) rather than the typical miter gates to close the 110-foot wide lock, the first use of this technology (USACE-Pittsburgh 1982:2). When the lock was open, the rolling gate was housed in a recess in the landward lock wall (USACE-ORD 1979:25). A complete account of the history, construction, operation and influence of the lock and dam is contained in Leland R. Johnson's study, *The Davis Island Lock and Dam, 1870-1922* (USACE-Pittsburgh 1985).

Merrill suggested deferring the building of additional Ohio River locks and dams until experience was gained in operating this prototype. Corps engineers made several changes in design based on this monitoring. Perhaps most notably, wicket operation from a service bridge, as found in France, was eliminated. The bridge had been damaged by barges on several occasions and almost destroyed by the debris carried by the crest of the 1889 Johnstown flood. Instead, at later dams, wickets were raised and lowered by lock personnel on maneuver boats. The accumulation of debris at the dam also led to the installation in 1889 of a drift gap, controlled by beartrap gates, through which floating logs and other large debris could be flushed (USACE-ORD 1979:25).

Heavy scour below the dam was stopped by sinking barges loaded with stone, and it became standard practice to build stone riprap aprons below each Ohio River dams. The first rolling gates were built of wood and mounted on metal wheels and axles. Based on the rate of

Plate 1-7. Davis Island Lock and Dam (Postcard collection, Historical Society of Western Pennsylvania).

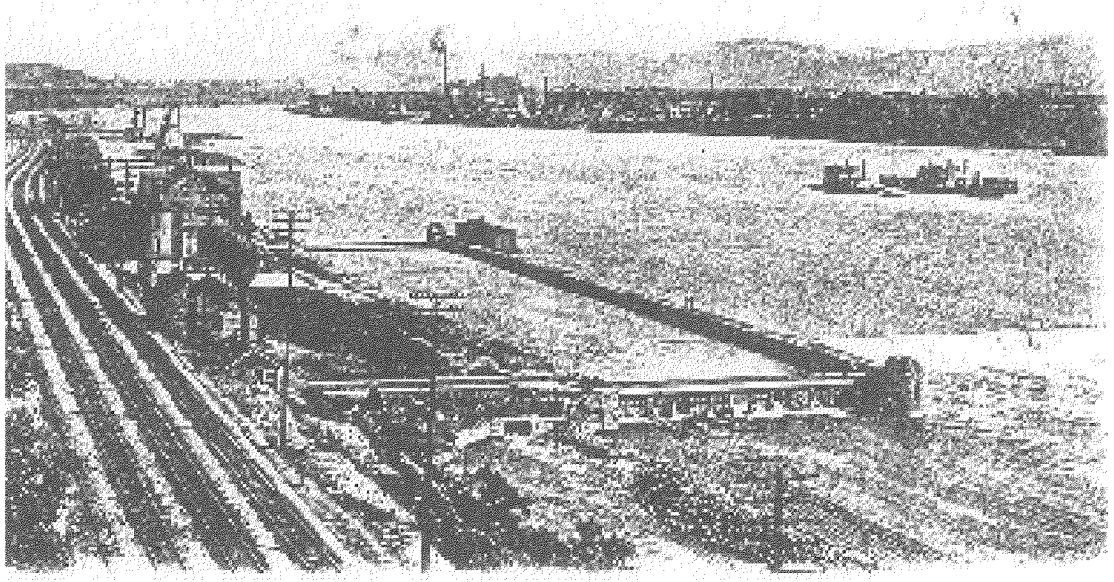

Plate 1-8. Dashields Lock. General view looking upstream (Pittsburgh District, U.S. Army Corps of Engineers 1952).

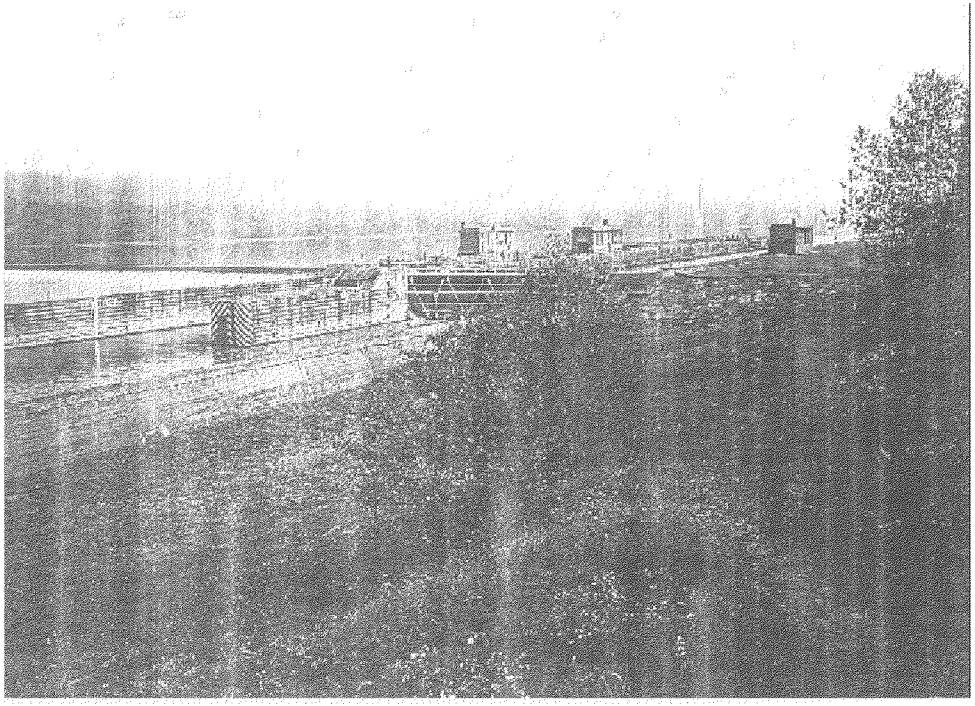

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Plate 1-9. Louisville and Portland Canal. New lock. From U. of Louisville Photographic Archives.

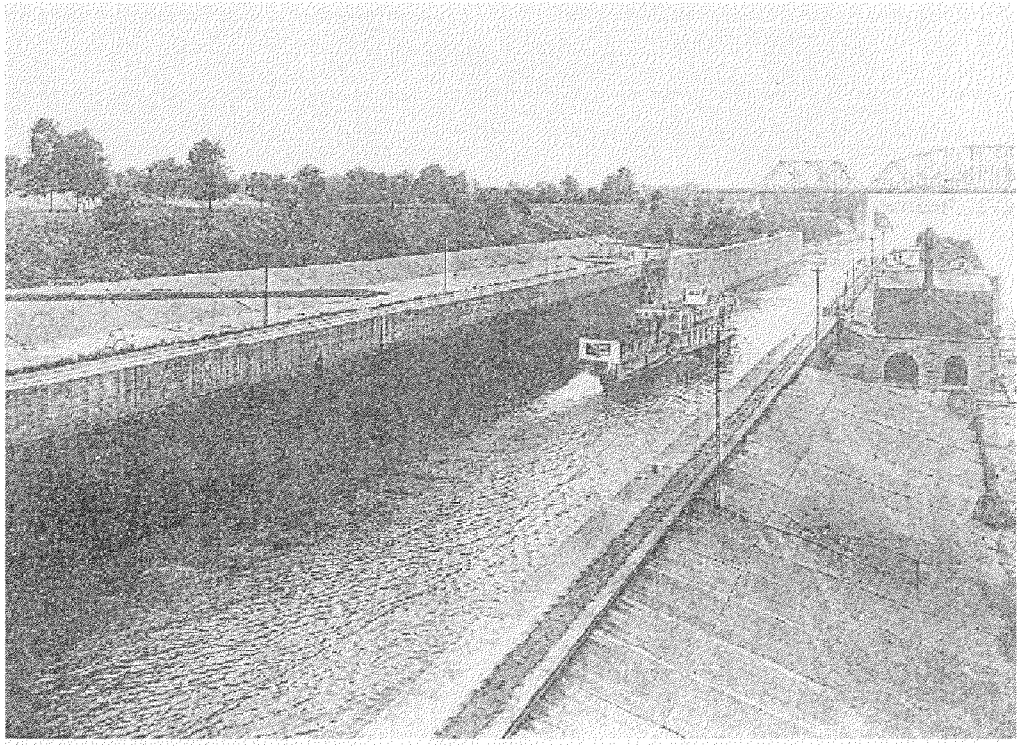

Plate 1-10. Louisville and Portland Canal. South wall, old canal (Louisville Electric Company 1926). From U. of Louisville Photographic Archives.

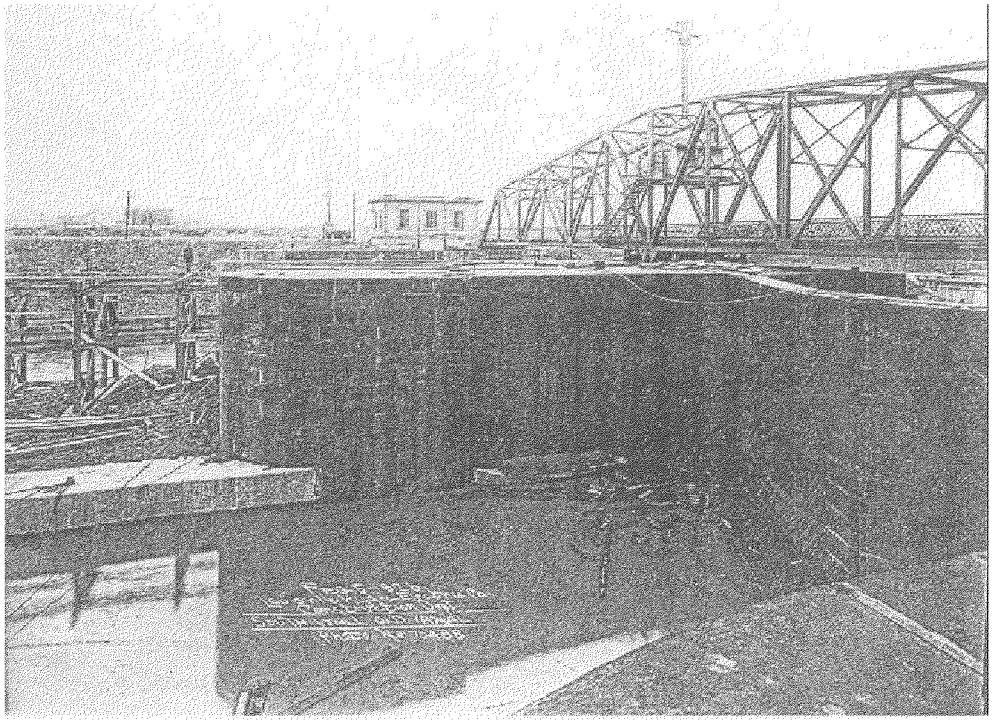

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Figure 1-2. Davis Island Lock and Dam. Plan of lock (reprinted by USACE-Pittsburgh 1985).

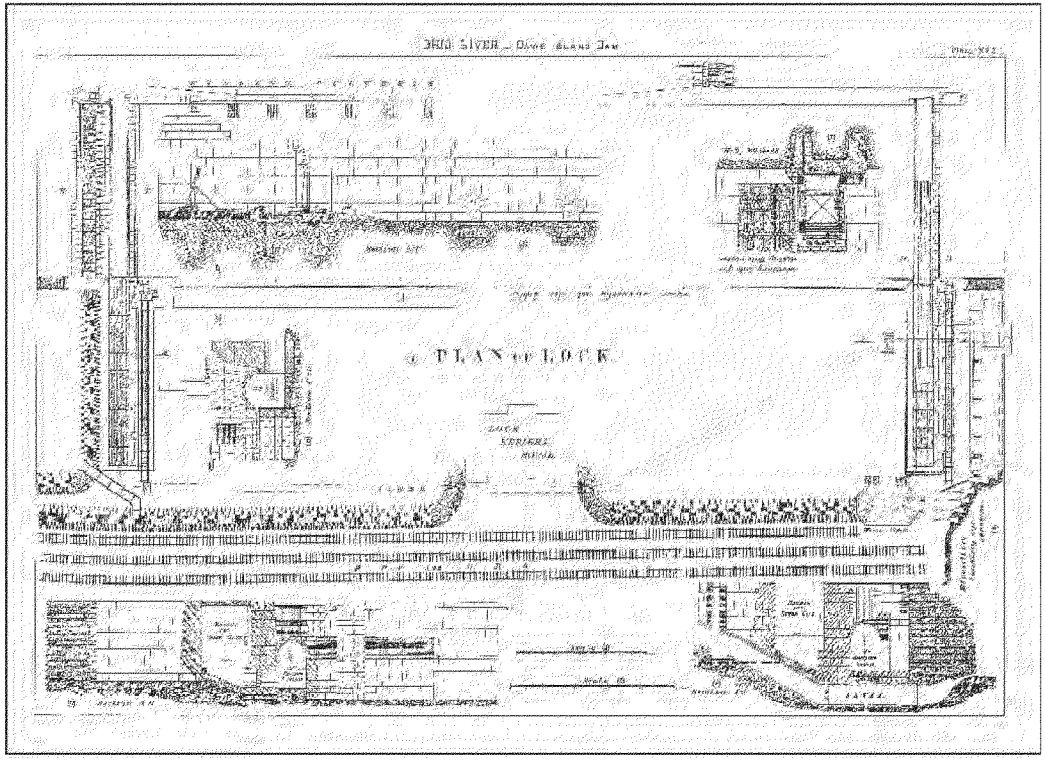

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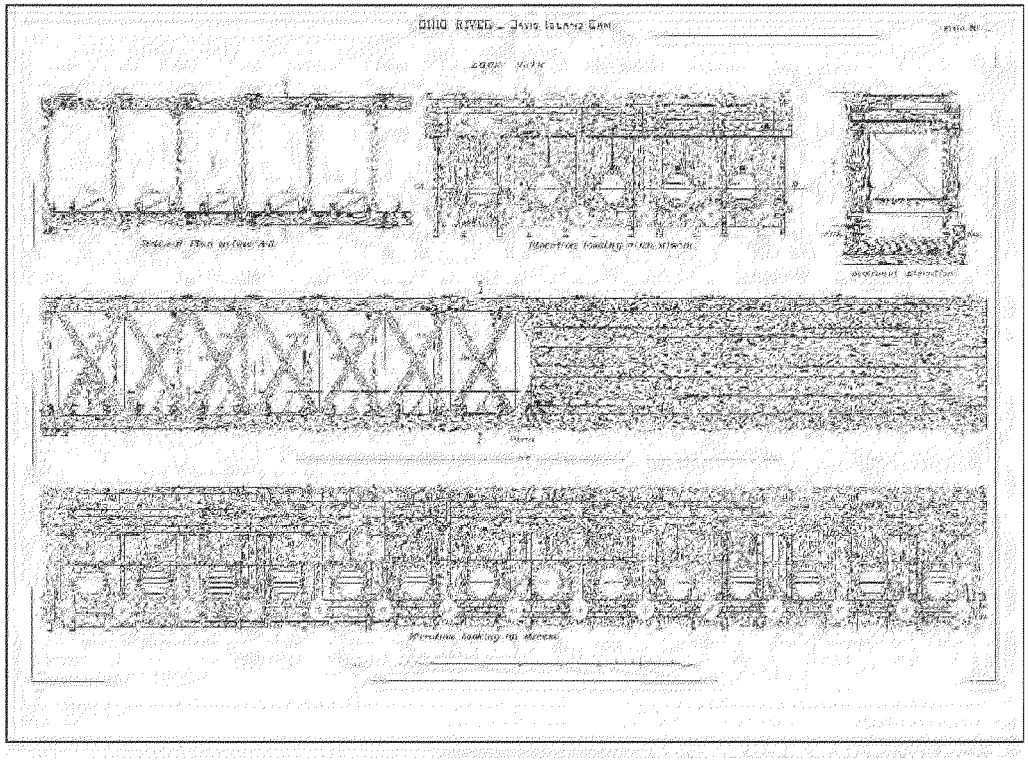
Figure 1-3. Davis Island Lock and Dam. Lock gate (reprinted by USACE Pittsburgh 1985).



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deterioration of Davis Island's gates, later rolling gates were constructed of metal (Johnson 1977:94).

Continuation of Slackwater Construction

The River and Harbor Act of August 11, 1881 directed appointment of a Board of three engineer officers to examine and report on the feasibility and advisability of improving the Ohio River below Pittsburgh with movable dams. The Board recommended the construction of four dams below Davis Island, No. 5 being located just below the mouth of Beaver River (Taft 1908:10).

Sentiment of rivermen began to change to favor canalization after the Davis Island Lock was in operation. During an unexpected flood in July 1888, one hundred coal barges sank along the Ohio River, but no barge in the harbor behind Davis Island was lost. Industry located along the Davis Island pool benefited from a more reliable water supply. Fears that the pool would be stagnant and a breeding ground for disease proved unfounded. Instead, sewage and other obnoxious effluents which had formerly rotted along the shoreline during low water periods were washed away. Both rivermen and industrialists urged the extension of canalization downriver (Johnson 1977:95).

In 1888, Congress authorized a study of an extension of the 6-foot minimum river depth down the upper Ohio River. The following year, a Board of Engineers concluded that it was "practicable, feasible, and advisable to improve the Ohio River from Pittsburgh to a point just below the mouth of the Beaver River...by the construction of movable dams" (as cited in USACE-ChE 1892:2534). Drawing upon Lt. Colonel William E. Merrill's 1891 survey, the location of the five additional locks and dams were selected as Merriman's Bar, the Trap. Logstown Bar, just below the Beaver River, and below Raccoon Rapids (USACE-ChE 1892:2534-2535). Lock and Dam No. 6, named the Merrill Dam in honor of the late engineer, was constructed first. First appropriations for its construction were made in 1890, but small annual appropriations delayed the project's completion until 1906 (Robinson 1983:27).

The high cost of the locks and dams, approximately $1 million for each complex on the upper Ohio, made Congress reluctant to appropriate additional construction funds. To lobby for funding, rivermen and shippers from Illinois, Indiana, Kentucky, Ohio, Pennsylvania, and Virginia organized the Ohio Valley Improvement Association (OVIA) in 1895. Colonel John L. Vance of Gallipolis, Ohio was named its first president (Ambler 1932:409; Mueller 1952:180). The Association sponsored river trips for members of Congress, dramatizing the Ohio River valley's need for improved waterways (Johnson 1977:96). The first appropriations for locks and dams 2 through 5 were made in 1896.

Army Engineers completed a survey of the river from the mouth of the Beaver River to Marietta, Ohio in 1898. The following year, they recommended the construction of twelve more locks and dams (7 to 18) that were authorized in 1899. The Army also made the decision to build the first structures below major riverports and the mouths of large tributary streams, rather than in downstream order. Dam No. 13 at Wheeling and No. 18 at Marietta were to be built first followed by those in between (Johnson 1977:96).

By 1900, coal barge tows had increased in number and draft. Merrill's successor in charge of the river's canalization, urged that the minimum channel depth be increased to nine feet. That depth, he reported stood "a fairly good chance of given all the draft that can go through the Mississippi

River during the life of the present generation and perhaps during the present century" (Johnson 1991:195).

The Corps continued the river survey from Marietta to Cincinnati in 1900. The following year, the building of twenty additional locks and dams was recommended (Nos. 19 to 38) with the dams below Parkersburg and the Little Kanawha River, Gallipolis and the Kanawha River, Ashland and the Big Sandy River, Portsmouth and the Scioto River, and Cincinnati and the Miami River to be constructed first. By the end of 1901, Davis Island had been completed, Nos. 2 through 6 were under construction and 32 more complexes had been authorized (Johnson 1977:96).

While plans proceeding for the continuation of canalization, representatives of river interests pointed out that large barge tows then in operation often drew more than six feet of water. These interests, led by the OVIA, asked Congress to consider creating a nine-foot minimum depth for the entire Ohio River channel. In the River and Harbor Act approved March 3, 1905, Congress authorized an analysis of the feasibility of extending the slackwater system to the mouth of the Ohio. The Chief of Engineers appointed a board of officers to conduct this study. Named the Lockwood Board after its chairman Lieut. Col. D.W. Lockwood, the board included Lieut. Col. Ernest H. Ruffner, Lieut. Col. Clinton B. Sears, Major George A. Zinn, and Major William L. Sibert (Taft 1908:1-2).

The board estimated that completion of a 6-foot project the length of the Ohio River, including the construction of 45 locks with movable dams, would cost $50,962,266, while the 9-foot project would require the construction of 54 dams and associated locks at the cost of $63,731,488. The board noted that the latter alternative would result in greatly increased economic benefits by encouraging the development of bulk traffic volumes and urged its approval (Robinson 1983:28; Taft 1908:2-3).

The continuing canalization project was not without its critics. One wrote that the project was doomed to become a disastrous "monument to the folly of man" as river traffic would never justify the expense incurred in building it (Johnson 1977:98).

The River and Harbor Act of March 3, 1909, provided $160,000 for the cost of surveying the location of Locks and Dams 9 to 29 and preparing plans and estimates for the locks and dams. This survey was conducted by Captain Lytle Brown of the Corps of Engineers. The report, issued by Congress in 1912, included a thorough discussion of the engineering aspects of the proposed lock and dam complexes (Stimson 1912).

In the River and Harbor Act of 1910, Congress authorized construction of the 9-foot channel project. A total of $1,150,000 was appropriated to be used for the purchase of sites for eighteen locks and dams, numbered 9, 10, 12, 14, 15, 16, 17, 20, 21, 22, 23, 24, 25, 27, 28, 29, 41, and 48, and toward the construction of locks and dams 7, 9, 10, 12, 19, 20, 29, 41, and 48 (USACE-ORD 1979:28).

At Louisville, the complex was designated Locks and Dam No. 41 in 1914. The existing 100 by 600 foot lock was completed in 1921, and the old two-flight lock was replaced in 1930 by the existing 56 by 360 foot lock. Between 1925 and 1927, a movable weir dam with a navigable pass was built in conjunction with a hydroelectric power project of the Louisville Gas and Electric Company (USAED-L 1995).

Even as construction of the slackwater system continued, river traffic declined. In 1917, cargo carried on the river reached a low of about 4.6 million tons, a nadir caused largely by the abrupt halt of coal shipments from Pittsburgh to New Orleans. The turning point for the slackwater system was during World War I. Wartime shipping overburdened the country's land transportation system and by 1920, cargo volume on the Ohio River had risen to almost 9.4 million tons, a total that increased further 10.8 million tons in 1924 (Froggett 1926a), 16 million tons by 1925 (Froggett 1926b), and 22.3 million tons by 1930 (Robinson 1983:28-29; USACE-ORD 1979:22). Where traffic once consisted primarily of coal and steel products moving downstream, new products were being added as the century progressed. Freight soon included petroleum and its products, iron and steel, dry and liquid chemicals, grain, cement, and a variety of other items (Gaum 1970:487), and upstream traffic substantially increased in volume.

By 1926, the 9-foot slackwater system had been completed as far as Cincinnati. Construction continued rapidly downriver and was officially completed in 1929. As completed, the system included 51 movable (wicket) dams, each with a 110 by 600 foot lock chamber. Of the 54 structures originally contemplated, numbers 40, 42 and 54 were eliminated through modification of other projects (Robinson 1983:29; USACE-ORD 1979:29). The total cost of the project was $125 million, one-third of the cost of the Panama Canal (Johnson 1977:131).

President Herbert Hoover, an engineer himself, put the project in historical perspective at a dedication ceremony in Cincinnati in October 1929:

> While I am proud to be the President who witnesses the apparent completion of its improvement, I have the belief that some day new inventions and new pressures of population will require its further development. In some generations to come, they will perhaps look back at our triumph in building a channel nine feet in depth in the same way that we look at the triumph of our forefathers when, having cleared snags and bars, they announced that a boat drawing two feet of water could pass safely from Pittsburgh to New Orleans. Yet for their times and means they, too, accomplished a great task. It is the river that is permanent; it is one of God's gifts to man, and with each succeeding generation we will advance in our appreciation and our use of it. And with each generation it will grow in the history and tradition of our Nation (as cited in Johnson 1977:132-133).

Even as the original slackwater system was under construction, the Corps began planning Hoover's predicted improvements on the portions of the river closest to Pittsburgh.

Replacement of the Original Locks and Dams

Movable dams in the upper part of the river proved unsatisfactory. The river was so variable in flow that frequent manipulation of the dams was necessary. In addition, the steepness of the bottom slope made it extremely difficult to maintain a constant depth of nine feet (Kutz 1930:437). A 1916 report indicated that Dams No. 1 and No. 2 were in poor condition and would require reconstruction in the near future (Baker 1916:2). Plans began to be developed to replace the movable dams with fixed crest dams in the section of the Ohio River nearest Pittsburgh.

The Baker report cited additional reasons for the replacement of the Upper Ohio movable dams with fixed dams:

> Following the construction of Dams 2, 3, 4, etc., the coal men and vessel interests have found it advantageous at times to assemble their tows farther downstream than formerly, for this could be done without any appreciable increase of cost, owing to the fact that the vessels were always in commission and operating charges continuous. The distance downstream thus secured was that much gained in the fleet's run, and a further advantage was that much of the former congestion in pool No. 1 was avoided. As a result of this experience the sentiment has been growing among those interested in this traffic that the establishment of permanent pools by fixed dams upon this portion of the river would be a gain to the commerce originating in the vicinity of Pittsburgh. The construction of permanent, or fixed, dams would also permit the establishment of factories and large industrial plants requiring great quantities of water along the upper Ohio... (Baker 1916:6).

The report included the following recommendations:

> (a) That the Secretary of War be given authority...to cause fixed dams to be built in the Ohio River wherever such fixed dams would be more advantageous than movable dams, and that such authority be secured by the first bill in Congress to which its enactment would be germane.
>
> (b) That a fixed dam at or near Emsworth, Pa., be built at an early date to take the place of existing Dams 1 and 2 (as cited in USACE-ORD 1979:29).

In 1917, President Wilson signed the bill appropriating the funds necessary for the construction of the first and longest fixed dam on the Ohio River at Emsworth, Pennsylvania (USACE-Pittsburgh n.d.:22).

Dams 1 and 2, the structures closest to Pittsburgh, were replaced in 1921 by the non-navigable, fixed concrete Emsworth Locks and Dam at Mile 6.2 of the Ohio River. Dashields Lock and Dam, similar in construction to Emsworth, was placed in the system at Mile 13.3, taking the place of Lock and Dam 3 (USACE-ORD 1979:30).

The site selected for Emsworth was at Neville Island, where the existence of channels on either side of the island necessitated the building of dams on both channels. Because traffic could not be passed through the dam should the lock be closed in an emergency, two locks were built, one with the Ohio River standard 110 by 600 foot dimensions and the other with the standard 56 by 360 foot Monongahela River dimensions. These locks opened for navigation on September 1, 1921 and were the first double locks on the river (USACE-ORD 1979:31).

Construction of Dashields Locks and Dam at Deadman's Island (Plate 1-8) was approved by the Chief of Engineers in 1926. The complex was named for pioneer area resident David A. Shields. The dam is 1,585 feet long and it served to submerge a stretch of rapids that had become hazardous when the wickets of former Dam No. 3 were down. The locks marked the first use of cast steel armoring for exposed vertical corners of lock walls, a feature that later became standard on all inland waterways (USACE-ORD 1979:31).

In 1921, an Ohio River standard 110 by 600 foot lock was opened at Locks and Dam No. 41 in Louisville (Plate 1-9). In 1930, a 56 by 360 foot auxiliary chamber was completed to replace the old two-flight lock structure (USACE-ORD 1979:35). The auxiliary lock was built on the lower

part of the old, two-flight lock chamber. Part of the walls of these old chambers were used as the upper guide walls into the new lock (Plate 1-10) (Rhett 1971:VI-2).

During the 1930s, two additional replacement projects were begun: the high-lift Montgomery and Gallipolis locks and dams. Construction of Montgomery Locks and Dam (Plate 1-11), located at river mile 31.7, commenced in 1932. The structure was opened for use in June 1936, replacing locks and dams 4, 5, and 6. The dam, 1,379 feet in length, includes ten 100-foot vertical-lift gated spillway sections. The main lock has usable dimensions of 110 by 600 feet, while the auxiliary lock has usable dimensions of 56 by 360 feet (USACE-ORD 1979:33).

The Gallipolis Locks and Dam was placed in operation in 1937 at river mile 279.2, 14 miles downstream from the mouth of the Kanawha River. It replaced three dams on the Ohio River and three on the Kanawha River. The dam is 1,116 feet long and is equipped with eight roller gates, each 125.5 feet long, separated by nine piers (Plate 1-12; Figure 1-4). These are the only roller gates used on Ohio River dams. The two locks, as originally built, were 110 feet wide. The larger chamber measured the Ohio River standard 600 feet long, while the auxiliary chamber measured 360 feet long (Figure 1-5) (USACE-ORD 1979:33-34).

In addition to the new complex construction, the Emsworth Dam was rebuilt in 1936-1937 (Plate 1-13). The original dam was cut down and functions as the apron and baffle for the replacement structure (USACE-Pittsburgh 1971:5). The movable crest dam with vertical lift gates raised the upper pool by seven feet and allowed the elimination of the first locks and dams on both the Monongahela and Allegheny rivers. The main channel dam, measuring 967 feet long, includes eight 100-foot long vertical lift gates. The back channel dam has a length of 750 feet and includes five vertical lift gates and one movable trunnion Sidney gate (Plate 1-14) (USACE-ORD 1979:35).

Further improvements to the Ohio River Navigation System were driven by changes in tow size. As an economy measure, 1,000 foot tows had come into use, and these tows had to be broken up to pass through the 600-foot lock chambers of the Ohio River. Among the most serious bottlenecks on the river was at Louisville. There, the narrow two-mile canal approach, the high lift of 37 feet, and the slow lock filling and emptying characteristics combined to limit the physical annual capacity of the Louisville locks to about 19 million ton (Bruce et al. 1957:1239-3).

Ohio River Division studies indicated that lock dimensions of 110 by 1,200 feet, double the length of the old locks, could handle the largest tows operating efficiently on the river. The Division adopted these dimensions for the main lock at each new dam. An auxiliary lock, 110 by 600 feet, would provide additional capacity and serve traffic when the larger lock needed repairs. While the old locks had lifts of 7 to 8 feet, the new locks would have lifts ranging from 12 to 37 feet. An improved valve and culvert system would permit filling of these new, larger, locks in as little as eight minutes. The new dams were equipped with tainter gates that could be pivoted up and down to control the pool (Johnson 1991:202).

Plate 1-11. Montgomery Lock and Dam (Postcard collection of Craig D. Cicconi, U.S. Army Corps of Engineers, Pittsburgh District).

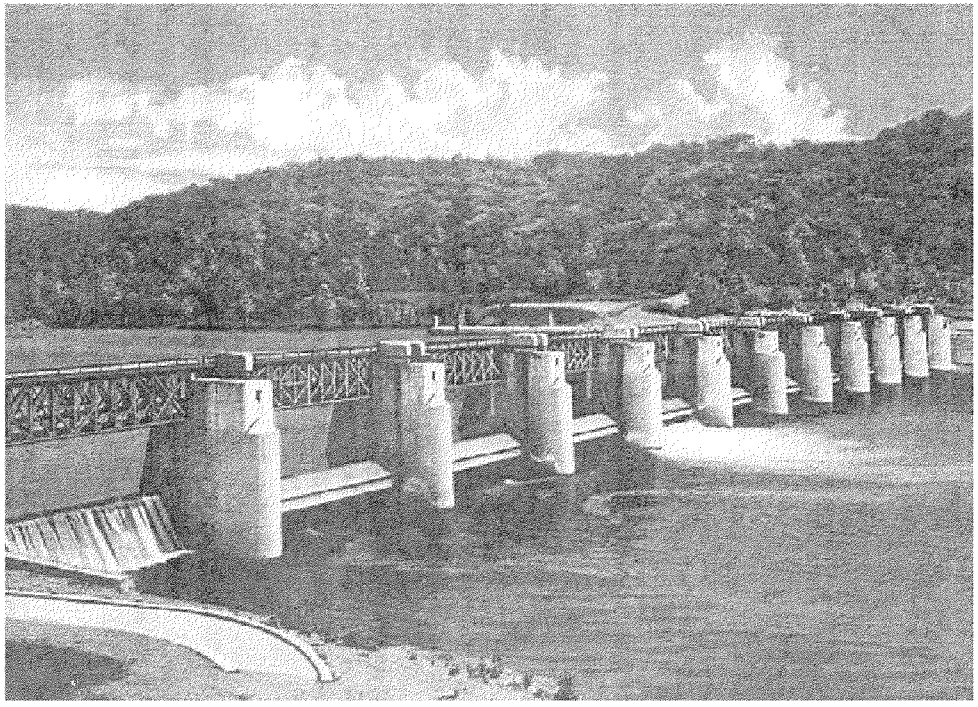

Plate 1-12. Gallipolis Dam (U.S. Engineer Office, Huntington 1937). (From Kemp 1993).

Plate 1-13. Emsworth Locks and Dam. General view of complex looking upstream (U.S. Engineer Office, Pittsburgh 1938). From the files of the Pittsburgh District, U.S. Army Corps of Engineers.

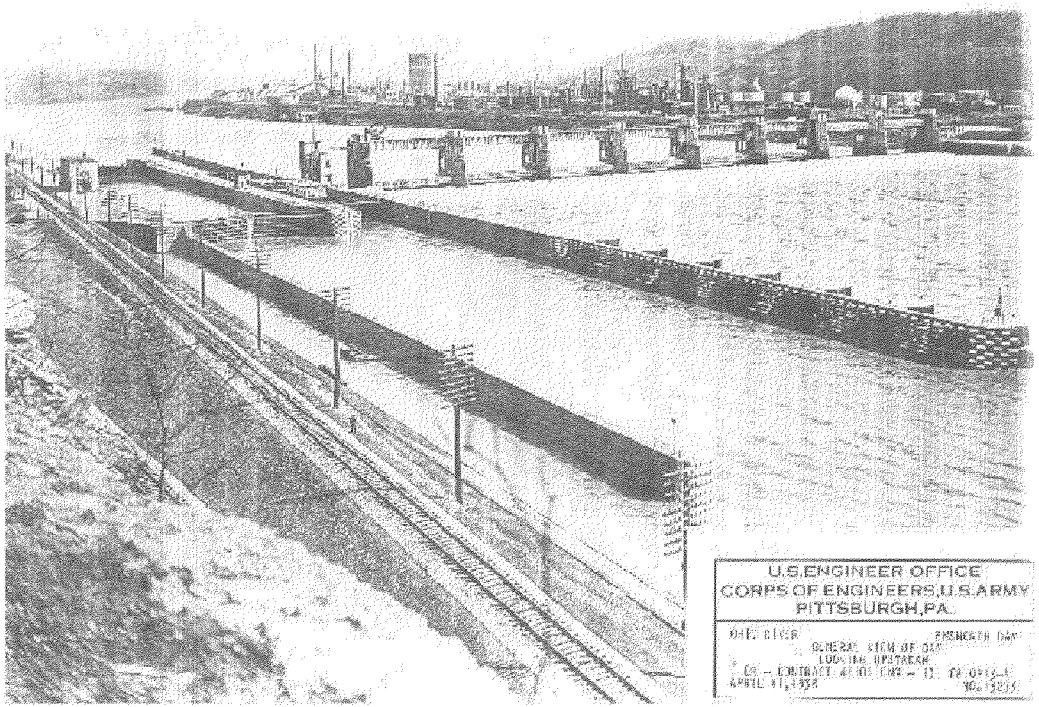

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Plate 1-14. Emsworth Dam. Back channel. Sidney gate shown open and rotated about two-thirds rotation limit (U.S. Engineer Office, Pittsburgh 1940). From the files of the Pittsburgh District, U.S. Army Corps of Engineers.

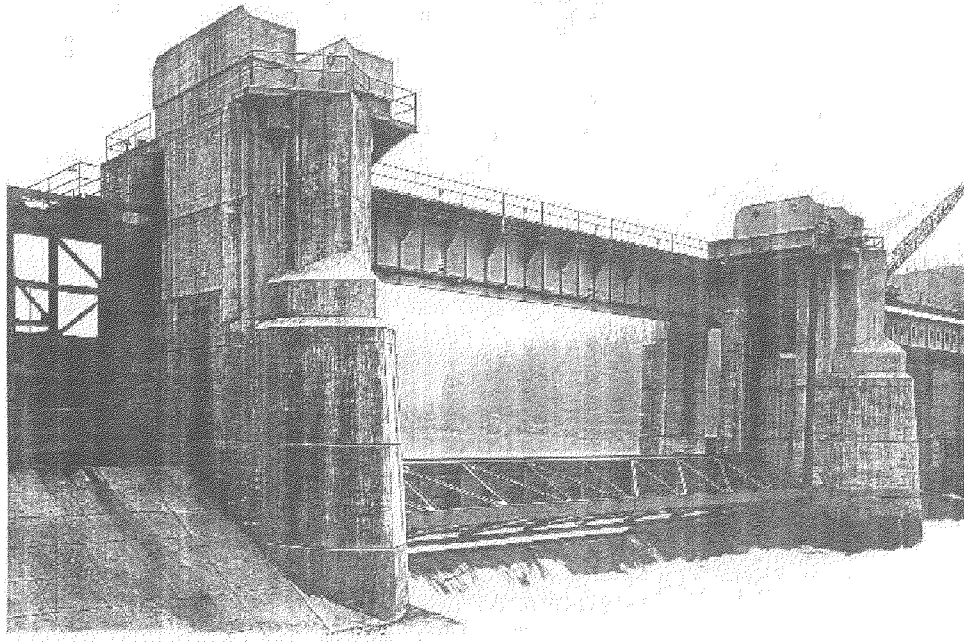

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Figure 1-4. Gallipolis Locks and Dam. Dam. General plan (U.S. Engineer Office, Huntington 1938). (From USACE-Huntington 1970).

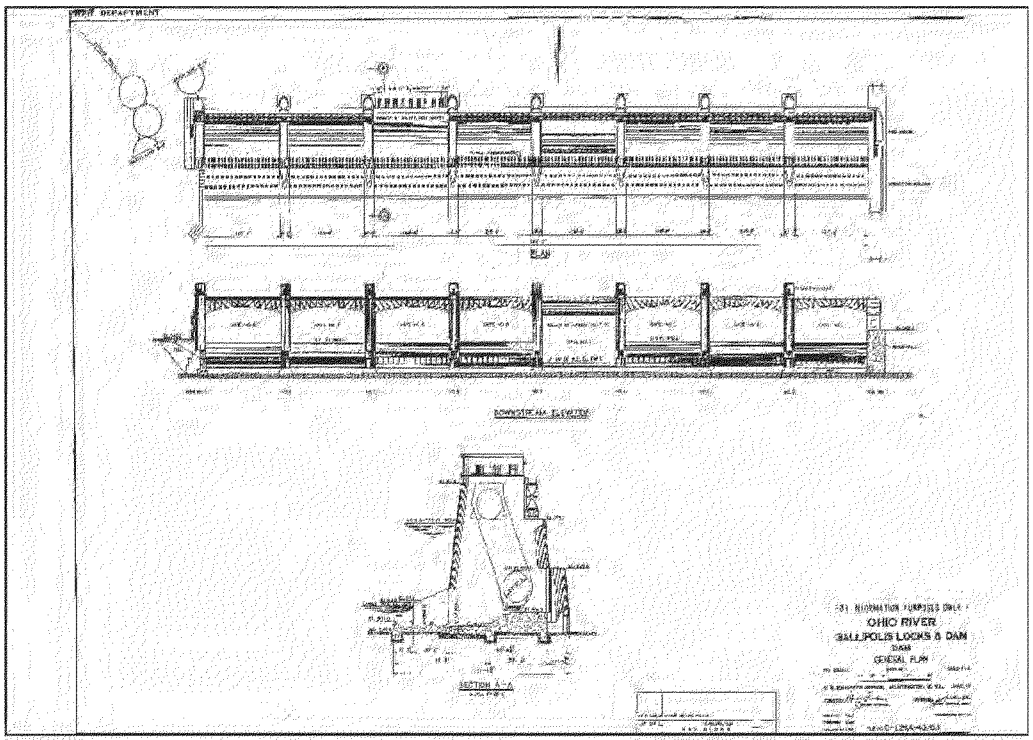

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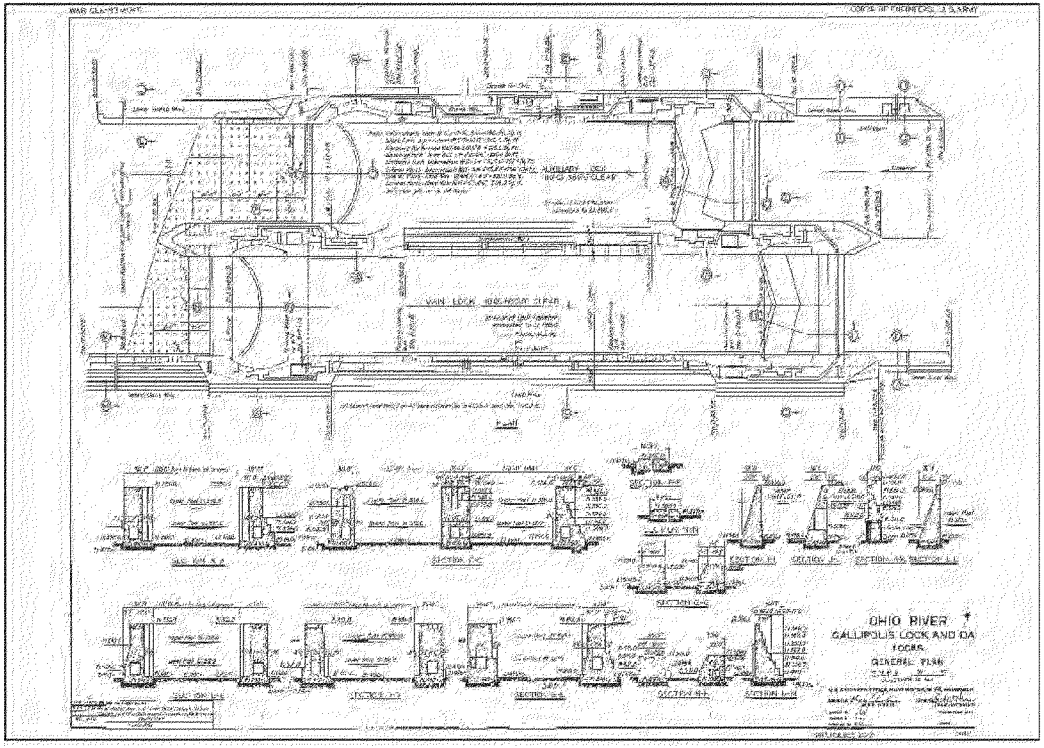
Figure 1-5. Gallipolis Locks and Dam. Locks. General Plan (U.S. Engineer Office, Huntington 1934). (From USACE-Huntington 1970).



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In March 1953, a full-scale modernization program of the Ohio River Navigation System was approved. Several factors drove the modernization program. Fewer locks and dams with locks of adequate size would reduce travel costs. Deeper pools impounded by higher dams would also reduce cost through the reduction of resistance to propulsion in deeper water. The preponderance of downbound loaded tows was a thing of the past. Riverside terminals and industries became increasingly dependent on uniform water supplies.

High-lift dams created longer, deeper pools, and the gates could be opened at high-river stages to pass river discharge without affecting flood levels (Robinson 1983:39). The wicket dam's provision of an open river at high water was no longer the advantage that it had been (Bruce et al. 1957:1239-5).

The designs of these projects called for non-navigable dams with fixed sills, equipped with tainter gates to regulate water flow. The gates are designed so that in times of flood they may be raised completely out of the water and leave clearance for the highest flood of record (Gaum 1970:491). The improved conduit and valve system **uses** reverse tainter valves in place of the older butterfly valves (USACE-ORD 1979:37).

The modernization program commenced with work on the Greenup Locks and Dam in 1954. By 1980, the program included the construction of 13 new high-lift lock and dam structures to replace 39 low-lift lock and dam structures. The thirteen new dams have lifts ranging from 16 to 35 feet. In addition, a new 1,200 foot lock was added at Louisville (McAlpine Lock) (USACE-ORD 1979:38). Other improvements at Louisville included rehabilitation of the existing locks and widening of the canal from 200 to 500 feet (USACE-Louisville 1995).

Greenup Locks and Dam were authorized to replace locks and dams 27, 28, 29 and 30 on the Ohio River and No. 1 on the Big Sandy River. Construction began in October 1954. The locks were placed in operation in November 1959, and the pool was raised to its full height in June 1962. New Cumberland Locks and Dam were authorized to replace locks and dams 7, 8, and 9. The locks opened for traffic in November 1959. Markland Locks and Dam, located at river mile 531.5, were approved by the Secretary of the Army on March 11, 1953. Construction of the complex began in March 1956. The locks were completed in May 1959, while the dam was completed in June 1964. Captain Anthony Meldahl Locks and Dam were authorized as a replacement for locks and dams 31, 32, 33 and 34. Construction began in April 1958. The locks were placed in operation in November 1962, while the dam was placed in operation on December 22, 1964. Pike Island Locks and Dams were authorized to replace locks and dams 10 and 11. Construction began in 1959, and the locks were opened in November 1963. John T. Myers Locks and Dam were authorized as a replacement for locks and dams 47, 48, and 49 in September 1958. Construction commenced in June 1965, and the project was completed in April 1985. The Cannelton Locks and Dam, located at river mile 720.8, were approved as replacements for locks and dams 43, 44 and 45 on January 27, 1960. Construction began in May 1962 and was completed in December 1983. Belleville Locks and Dam were approved as a replacement for locks and dams 17, 18, 19, and 20 on the Ohio River, Dam No. 1 on the Little Kanawha River and Dam No. 1 on the Muskingum River. Construction began in May 1962. The locks were placed in operation on October 12, 1965, while the dam pool was raised to full height on November 1, 1968. Racine Locks and Dam, located at river mile 237.5 replaced locks and dams 21, 22, and 23. Construction began in May 1964. The locks were placed in operation in December 1967, and the pool was raised to full height in August 1971. Newburgh Locks and Dam, located at river mile 776.1 were authorized as a replacement for locks and dams 46 and 47 in April 1962. The project began in April 1965 and was completed in October 1986. Willow

Island Locks and Dam replaced locks and dams 15, 16, and 17. Construction began in January 1967. The locks were placed in operation in January 1972, while the dam construction was completed in 1976. Hannibal Locks and Dam were authorized to replace locks and dams 12, 13, and 14. Construction began in 1967, and the locks were opened to river traffic in 1972. Smithland Locks and Dam, located at river mile 918.5, were authorized in December 1965 as a replacement for locks and dams 50 and 51. Project construction began in 1970 and was completed in November 1980. Smithland was the first Ohio River project to be built with twin 110 foot by 1,200 foot locks.

Construction on replacement locks at Gallipolis (present Robert C. Byrd Locks and Dam) began in late 1987. The new 110 x 1200 and 110 x 600 foot locks were opened in January 1993. Rehabilitation of the dam began in August 1992.

Construction has begun for a 1,200 by 110 foot concrete lock to replace the 600 foot and 360 foot locks at McAlpine locks in Louisville. The project will also involve replacement of an existing access bridge with a fixed, concrete and steel arch bridge spanning both the existing and new lock. Completion of this project is scheduled for 2006-2007 (USACE-Louisville 1999a).

Construction of the Olmsted Locks and Dam, a project that will replace the last of the numbered locks, #52 (Plate 1-15) and #53, began in 1992. This complex, when completed, will consist of twin 110-foot wide by 1,200 foot long lock chambers, and a dam with a 2,200 foot navigable pass and 425 feet of fixed weir. Completion of the entire project is scheduled for 2006 (USACE-Louisville 1999b).

Lock Sizes and Riverboat Technology

Prior to 1811, no powered vessels plied the inland rivers of the United States (Dyer 1956:1122). Flatboats and keelboats constituted the principal means of transportation on the Ohio River. Flatboats floated with the current with control limited to steering, while keelboats were the only sizable craft capable of moving cargo upstream (USACE-ORD 1979:6). Coal was shipped down the Ohio as early as 1793 by the Army Quartermaster Department to supply garrisons at forts on the frontier (USACE-ORD 1979:19).

Commercial coal shipments began on the Ohio in 1814 when the first coal from the Monongahela was floated down the Ohio River. Early shipments were transported in roughly framed and planked coalboats that were sold along with the coal at their destination. These boats measured about 80 feet long by 18 feet wide and drew 40 inches. Later boats were built with a length of 175 feet and a width of 26 feet. These vessels drew 8 feet when fully loaded with 24,000 bushels of coal. The boats were generally lashed together in pairs and floated downriver at high water stages (USACE-ORD 1979:19).

According to river historian Frederick Way, Jr., steam power was introduced on the Ohio and Mississippi rivers in 1811, when the first river steamboat, the *New Orleans*, was built in Pittsburgh, Pennsylvania (Way 1990:xi) and descended the Ohio River. Measuring 138 feet long and of 300 ton burden, its hull design made it impractical to operate in shallow water. Within a few years, steam-powered flatboats first appeared on the river. The first documented steam flatboat, the *G. Washington*, traveled the river in 1816. Entrepreneurs soon started packet boat lines to serve growing river towns. By 1819, 63 steamboats were in use on the Ohio River and connecting waterways (Loveland and Bailey 1949:171; Pence 1929:17).

Steamboat and flatboat traffic grew dramatically in the 1820s. Steamboat tonnage on the Ohio and Mississippi River systems totaled 25,700 tons in 1827, and about 7,000 flatboats navigated the rivers in the same year. A total of approximately 537,000 tons of freight valued at over $50 million was transported on the rivers in that year (Johnson 1975:74).

Leland Johnson summarized the importance of the steamboat to the economy of the nineteenth century Ohio Valley:

> Nearly 6,000 steamboats were built along the inland rivers between 1820 and 1880, and, from first to last, about three-fourths were built in the Ohio valley. The steamboat construction boom gave an enormous boost to Ohio valley industrial development, and the speedy, economical transportation the steamboats furnished accelerated commercial growth and ended the frontier isolation of the region (as cited in USACE-ORD 1979:9).

The Ohio River steamboat was a flat-bottomed vessel with a long and slender hull and ends modeled for ease of entry and run. The steamboat hull measured six to nine times as long as deep. To stiffen the flexible and lightly built wooden craft, the hogchain system of bracing was developed. Hogchains were wrought iron rods firmly fitted at the forward and aft ends of the hull led up over tall timber braces. The main deck was open with all space not occupied by boilers and machinery used for stowing freight (USACE-ORD 1979:9).

During much of the nineteenth century, commerce and industry were largely dependent on water transportation for the movement of both raw materials and finished products, as well as passengers. Steam packets moved most of the cotton from the South, timber and lumber from the forests and sawmills, and much of the coal from mines to market (Dyer 1956:1122-3).

With the growth of the railroad during the nineteenth century, commodity shipment began to shift to land-based transportation. A 1908 report chronicled this shift:

> From the beginning the railroad was a reliable system of transportation, and this reliability caused a gradual transfer to it from the intermittently navigable streams of the shipment of the more expensive grades of commodities—commodities that could stand a high freight rate and which demanded sure delivery in a reasonable time.
>
> As the railroad, paralleling the intermittently navigable stream, increased in efficiency, it continued to take from that stream the transportation of articles of less and less value, until finally there was generally left to the stream only the handling of the cheaper, bulkier commodities, like coal, the original cost of which was small and the loss consequent upon holding same in boats until the river reached a navigable stage was small (Taft 1908:16).

W. Milnor Roberts wrote in 1866 that one-way coalboats were gradually being superseded by steamboats towing fleets of coal barges downriver and returning the empty barges upriver for reuse. By the 1840s, it became common practice to place barges ahead of steamboats and push them downriver. Coal shipments down the Ohio River in the mid-1860s amounted to about 40 million bushels (or 1.5 million tons). At least 90 steam towboats were engaged in coal hauling (USACE-ORD 1979:19). By 1870, fleets of barges became common, and oil and coal provided much of the barge tonnage (Dyer 1956:1122-3).

To accommodate these barges, engineers planned 110 by 600 foot locks on the Ohio River. Ralph Bloor, in his pioneering study of inland waterway lock sizes, cited the reasons for this decision:

> In 1874 the engineers reported that locks should be large enough to pass a coal fleet of ten barges 24 ft by 130 ft., one fuel flat 22 ft by 100 ft, and one steamboat 48 ft by 230 ft. Two barges abreast would require locks 50 ft wide, but this would be too narrow for some of the steamboats then in use. If the barges were four abreast, a width of 100 ft would be needed, and it was doubted that a mitering lock gate could be designed for this width. Therefore, a lock 75 ft wide seemed desirable and the corresponding length needed was about 600 ft. To the coal carriers, accustomed to open-river operation, a lock 75 ft wide seemed hopelessly restrictive. In an effort to reach a satisfactory solution the engineers designed a rolling type of lock gate which they considered usable on locks wider than 100 ft, and in 1878 recommended a lock size 110 ft wide by 600 ft long. Thus was originated the largest commonly used lock size in the United States (Bloor 1951:878).

The 110 by 600 foot locks that were the original Ohio River standard were capable of passing an ordinary Ohio River towboat, ten barges and two flats in one locking. When loaded with coal, the barges had the capacity of 140,000 bushels or approximately 112 railcar loads (Anonymous 1905).

By the beginning of the twentieth century, the demand for speed in passenger transportation lessened the demand for packet boats. In many cases, rail lines offered more convenient and faster transport. In addition, the barge gradually replaced packet boats as the preferred means of freight transport on the river (Loveland and Bailey 1949:172).

In the early twentieth century, great fleets of wooden coal barges were assembled in the Upper Ohio Valley and towed as far as New Orleans. For example, in February 1907, the steamer *Sprague* took a tow from Louisville to New Orleans composed of 62 coal barges with a gross weight of nearly 70,000 tons (Dyer 1956:1122-3).

A 1908 study of the Ohio River included a description of the large towboats used on the river at that time:

> The larger sternwheel towboats on the Ohio River are equipped with from three to five balanced rudders. These rudders are from 20 to 30 feet long, shaped to the bottom of the boat, extend forward of the rudder post and project to the rear several feet beneath the stern-wheel. When the stern-wheel is reversed a strong current is deflected against the long rudder blades, thus facilitating steering....

A stern-wheel steamboat of about 1,000 horsepower will ordinarily leave the headwaters of the Ohio on suitable stages of water for southwestern points with a tow consisting of about 12 coal

Figure 1-6. Towboat "Exporter" and tow, Pittsburg[h] to Bellaire, Ohio (Taft 1908).

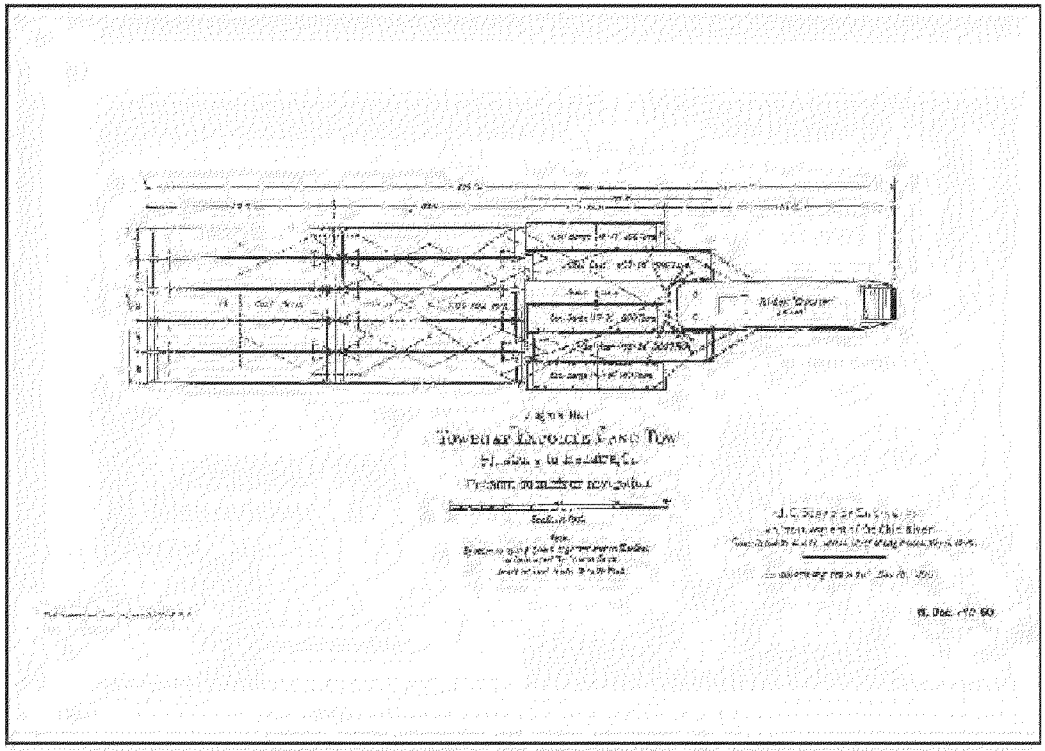
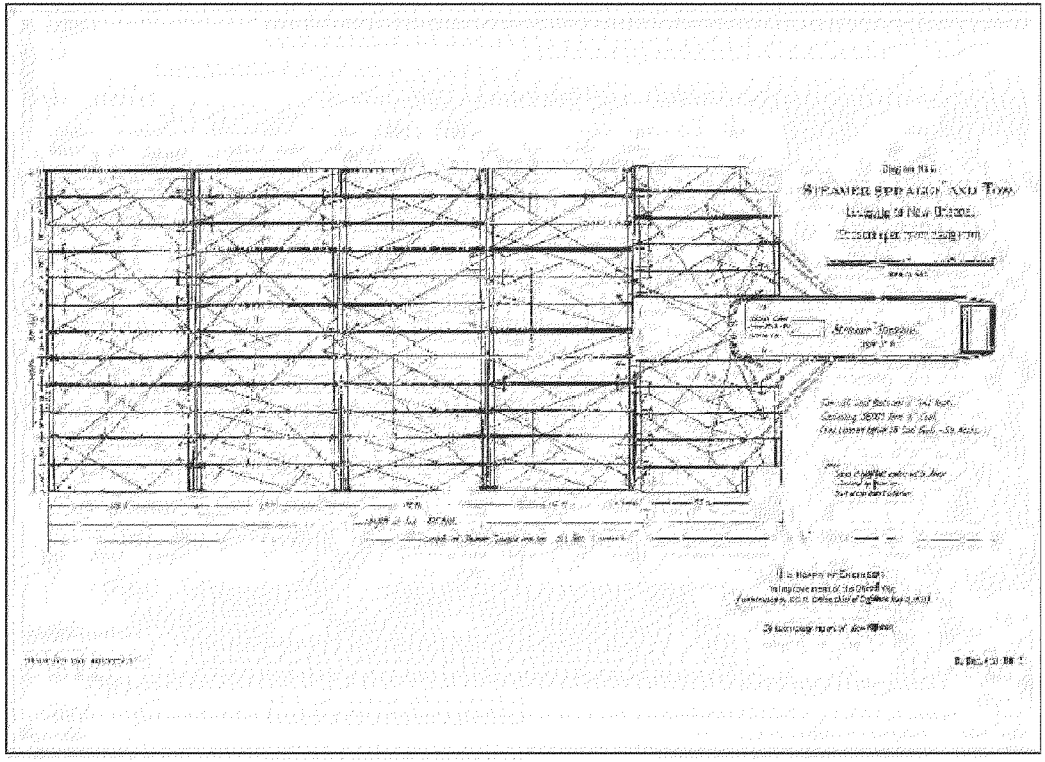


Figure 1-7. Steamer "Sprague" and tow, Louisville to New Orleans (Taft 1908).



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> boats and 3 barges [Figure 1-6]...After passing the Bellaire bridge, 96 miles below Pittsburg[h], 5 more coal boats will ordinarily be added to this tow, making a total of 17 coal boats and 3 barges, the cargo of which will be about 18,500 tons. Ordinarily this boat will proceed with the above tow to Louisville, Ky., and, after passing through the canal, will deliver its tow to a larger boat. From the canal at Louisville to New Orleans a boat of the most powerful class will tow from 30 to 60 coal boats, each boat being loaded with about 1,000 tons of coal or other similar commodities [Figure 1-7] (Taft 1908:19).

Two types of barges were then in use on the Ohio River, one drawing about six feet, while the other drew about eight feet (Taft 1908:33). Before many years passed, steel barges began to replace wood barges. By the late 1920s, more than 500 steel barges were launched each year (Deisler 1929:69).

By 1930, packet freight amounted to only 330,000 tons (1.6 percent) of total Ohio River cargo. Most of the cargo was carried in fleets of barges pushed by stern-wheel towboats.The barges were generally constructed of steel with a capacity of 800 to 1,000 tons each. Most were of the open type, with a small percentage specially constructed tank barges. Steam power still dominated in towboats, although diesel-powered boats were rapidly increasing in number. During low water season, tows were generally limited by the size of the locks, and cargoes ran between 8,000 and 10,000 tons. Larger tows, 12,000 to 14,000 tons, were not infrequent and had to be broken in two to pass through the locks (Kutz 1930:440). As towboat and barge technology improved and the demands for bulk shipment increased, barge dimensions also increased. The 24 foot wide barge grew in size to 35 feet, and the width of the tow grew to a maximum of 108 feet, allowing very little room for error in a 110 foot wide lock (Davis 1970:455).

Loveland and Bailey characterized river traffic in the immediate post-World War II era:

> The major portion of the present commerce on the river is handled in barge tows consisting of a towboat and one or more barges. Tows range up to 105 feet in width and 1,200 feet in length or larger. Tow from 600 to 1,200 feet in length require two trips for passing through locks of standard dimensions, 110 by 600 feet. Tows of sufficient size to require two trips (double lockage) are of common occurrence. Extremely large tows requiring triple lockages occur at rare intervals (Loveland and Bailey 1949:172-173).

Post war towbats used underwater screw propellers and often had a draft of seven to eight feet. Loveland and Bailey illustrated the evolution of the towboat by comparison of the *Sprague*, a steam-powered sternwheeler, and the *Esso Louisiana*, the diesel-powered boat that replaced her:

> The *Sprague* was constructed in 1902 and is 276 feet (315 feet overall) by 62 feet by 7.4 feet in depth, with double expansion steam engines 28-inch diameter (high pressure), 63-inch diameter (low pressure) by 12-foot stroke, developing 2,709 horsepower. The sternwheel on the *Sprague* is 38 feet in diameter by 40 feet wide. The *Esso Louisiana* is 166 feet by 36 feet by 10.5 feet in depth, with two diesel engines turning two underwater propellers and developing a total of 2,000 h.p. Although the *Sprague* is 110 feet longer and 26 feet wider, the *Esso Louisiana* is expected to out-perform her (Loveland and Bailey 1949:175).

In 1950, commerce on the river reached an all-time high. Over 48.5 million tons were carried over 8.8 billion ton-miles. Much of the increase in commerce can be attributed to increases in coal and coke shipments (Mueller 1952:183).

Major changes occurred in the design of barges following war's end. The old "Pittsburgh standard" barges had capacities of about 1,000 tons. By the late 1970s, four types of barges were employed on the Ohio River: 1) open hopper, 2) covered hopper, 3) deck, and 4) tank. Open hopper barges, used to transport bulk solid cargo dominate. Open hopper barges are built in three sizes, the standard, which measures 175 feet in length and 26 feet in width with a capacity of 1,000 tons; the jumbo, which measures 195 feet in length and 35 feet in width and has a capacity of 1,500 tons; and the super jumbo, which measures between 250 and 290 feet in length, from 40 to 52 feet in width, and has a capacity of 2,500 to 3,000 tons (USACE-ORD 1979:56).

Post World War II lock sizes were proposed by Ralph L. Bloor in a 1951 study. Bloor noted that, in 1945, the predominant width of Ohio River bulk cargo barges was either 26 or 27 feet width a lesser number 35 feet wide. The predominant width of tank barges was 35 feet with a lesser number 26 feet wide. He noted that a lock of 110 ft by 600 ft had been established as a kind of standard because it is wide enough to accept either the 26 ft barge or the 35 ft barge without wasting space. He concluded that for the larger river a lock length of 1,200 ft must be considered since tows of that length had already been operated to a limited extent by the early 1950s and future increases in traffic would make them more common (Bloor 1951:887).

By the late 1970s, downriver from Huntington, West Virginia, about two-thirds of the barges in use were jumbos, about one quarter were integrated chemical and petroleum barges (150 to 300 feet long, 50 to 54 feet wide, with capacities of 1,900 to 3,000 tons), and most of the remainder were standard barges. Upriver from Huntington, jumbos accounted for about half the total number, standards for about 30 percent, and integrated for most of the remainder. The average number of barges per tow was about eight. Coal tows of 20 to 24 standard barges or 15 jumbo barges were frequently seen (USACE-ORD 1979:57). The total amount of waterborne commerce on the Ohio River in 1977 amounted to over 151 million tons of which over half was coal and coke (USACE-ORD 1979:22).

Clearance in the 1,200 foot locks for some tows was as little as a foot on the sides and twenty feet in length. According to John Davis, tows carrying as much as 20,000 to 25,000 tons of flammable liquids were being used on the Ohio River that had lengths of 1,180 feet and widths of 108 feet (Davis 1970:457).

Traffic on the Ohio River grew 60 percent between 1983 and 1997. In 1997, over 271 million tons of commodities moved on the waterways of the Ohio River Basin of which, almost 240 million tons traveled on the Ohio River. The value of these commodities was almost $31.3 billion. Over 58 percent of the tonnage was coal, while aggregates accounted for almost 18 percent (Palmer 1999:3; USACE 1998).

OHIO RIVER NAVIGATION SYSTEM TECHNOLOGY

Locks

Lock Construction

The walls of Louisville and Portland Canal locks were constructed of cut stone masonry. Stone for these walls was quarried a few miles below the site and transported upriver. Later, limestone taken from the lock pits was used in the production of cement for use as a mortar to bind the masonry in the lock walls together (USACE-ORD 1979:17).

The first two locks constructed on the Ohio River (Davis Island and Lock #6 (Merrill)) also had walls of cut stone masonry. The next two locks constructed had walls of natural cement concrete faced with Portland cement, except in the lock chamber, where the walls were faced with timber. All later locks have walls constructed of concrete (Kutz 1930:434).

To prevent scouring and gouging of lock walls, those locks constructed beginning in the late 1920s had part of the lock wall faces protected against abrasion by horizontal lines of cast-steel fenders imbedded in the concrete (Kutz 1930:434). These cast-steel fenders were first used on the Ohio River.

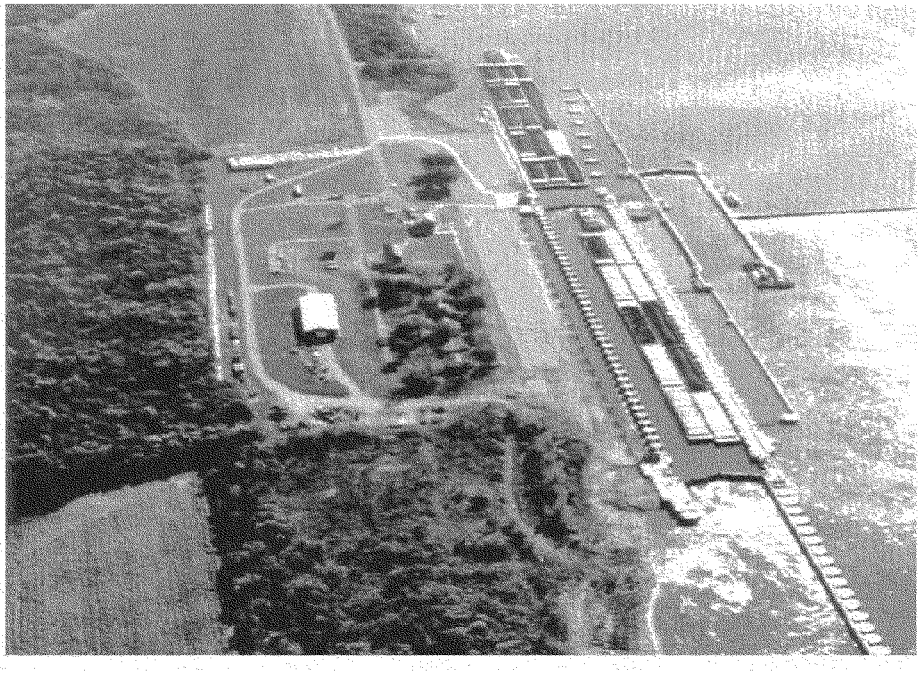
All the modern locks have concrete gravity lock walls. For example, at Meldahl locks, the land wall has a base width of 62 feet, the middle wall a base width of 67 feet and the river wall, a base width of 61 feet. Top widths range from 5 to 52 feet (Houck 1960:19).

In recent years, the Corps employed innovative techniques to construct a temporary 1,200 foot lock chamber at Locks 52 (See Plate 1-15). This long chamber was needed to alleviate congestion on the lower Ohio River. The construction involved the use of circular steel cells, not to serve as a cofferdam, but to serve as walls of the 1,200 foot lock chamber itself. The same technology was later used in a temporary 720 foot lock chamber at Monongahela River Locks No. 3. Leland Johnson described the technology in his history of the Louisville District:

> With lines of steel cells forming the walls, the lock could not be filled and emptied through the usual culverts inside concrete lock walls; the design therefore included an open flume down one side of the new lock walls with gates at each end controlling the flow of water through the flume (Johnson 1975:35).

The lock chamber was constructed with three lines of circular cells, two serving as lock walls and the third as one side of the flume and the retaining wall of the riverbank. Steel piling driven in a circle formed each cell. Each cell was filled with sand and capped with concrete. At the ends of the lock chamber, concrete monoliths provided anchorage for the lock gates and the gates controlling flow through the flume. The flume pit was floored with broken stone and the lock chamber was floored with pre-cast concrete blocks. The entire job required only 38 months from conception of the design to completion. It was recognized by the Chief of Engineers with his National Design Award of 1970 for the "innovative common sense" approach to a "unique engineering challenge" (Johnson 1975:35).

Plate 1-15. Aerial view of Locks and Dam No. 52. Note circular cells used in land lock. No date. From Louisville District, U.S. Army Corps of Engineers.



In the early numbered locks, guide and guard walls were originally constructed of timber cribs filled with stone. At Davis Island, these walls were eventually reconstructed in concrete and lengthened (Johnson 1985:73). Later numbered locks had concrete guide and guard walls.

The approach walls of some of the first replacement locks, such as Montgomery, were constructed of concrete founded on wood bearing piles. The approach walls at Deadman Island Lock were founded on concrete piers spaced 20 feet center to center and ranging from 16 to 27 feet high. Montgomery's approach walls were later extended. The upper guide wall extension is a concrete cap supported on steel sheet pile cells and diaphragms. The upper guard wall extension is a series of six individual circular, sheet pile cells filled with granular material and capped with concrete. The cells are tied together with a timber fender system (USACE-Pittsburgh 1972b:2; Casey 1929:444-445). The guard and guide walls at Dashields locks were constructed using a concrete cap on concrete piers (USACE-Pittsburgh 1972a:1).

At Hannibal locks, the upper guard wall is founded on isolated steel sheet piling cells providing ports beneath the walls. Later permanent steel sheet pile bulkheads were installed in the eight port openings immediately upstream of the river wall. The lower guard wall is founded on continuous diaphragm-type steel sheet pile cells. The approach walls are protected by wall armor of continuous bands of rolled structural steel (USACE-Pittsburgh 1973:6).

Modern locks such as Captain Anthony Meldahl used circular interlocking sheet steel piling guard and guide walls (Houck 1960:17). Another recently added feature of locks are floating mooring bits. For example at Smithland, sixteen floating mooring bitts are provided in each lock, eight in each wall. The bitts are similar to those installed at the Cannelton, Barkley, Hannibal and Opekiska locks (USACE-Louisville:Smithfield:E1).

Lock Gates

Rolling Gates

The first locks constructed on the Ohio River Navigation System used rolling gates (Figure 1-8). These gates were developed to span the unprecedented width of the Davis Island lock chamber. A rolling gate is a massive steel frame, sheathed on one side and running on ten pairs of flanged car wheels which rolls on a steel track carrying the gate from a recess in back of the land wall across the lock chamber. On most of the rolling gates, the wheels were constructed of cast iron, revolving on fixed axles. This mounting permitted ready replacement in case of breakage but caused more wear on the gate tracks than wheels rigidly connected to revolving axles. The gates were opened or closed by a chain or cable connected to a winding drum which, in turn, was gear-connected to a reciprocating engine actuated by compressed air (Kutz 1930:434).

In a report submitted in 1878, Major William E. Merrill discussed the reasons for his development of the rolling lock gate:

> The plan for a lock which was presented to the board in April 1875...contemplated a width in the clear of 78 feet and an available length of 630 feet. It was expected to accommodate a fleet of nine coal barges, in three ranks of three in a rank, a towboat in rear of the fleet, and a small fuel flat. It was known even then that coal fleets are not usually made up in this manner, but the lock proposed was believed to be as wide as it was practicable to make it with miter gates of such limited height.
>
> The coal trade objected strenuously to this arrangement of lock, and meanwhile, the officer in charge, recognizing the force of the objections to the lock as approved, endeavored to overcome them by an increase in width. After long investigation he decided to recommend a gate somewhat resembling a railroad car, which, when out of use, is housed in a recess in the bank, and when needed is run across the lock, thus shutting it up and acting as a gate (Stimson 1912:54).

The rolling lock gates consisted of three main parts: 1) a top truss which served to carry a portion of the water pressure to the lock walls; 2) a vertical water screen which served to close the lock and transferred one-third of the pressure to the top truss and two-thirds to the track; and 3) the truck and wheels.

William L. Sibert described the original Davis Island gates in a paper presented to the American Society of Civil Engineers:

> The original gates at the Davis Island Lock were made of pine timber. The top truss was of the Howe type, supported on posts so as to lie above the normal level of the upper pool. The posts extended below the level of the track, and their

> lower ends served as flanges for the wheels which were of the plain-tread type, traveling on a flat-rail track, the gauge of which was 11 ft. 6 in. ... The gate was moved back and forth by two chains, each chain being fastened at one end to an end of the gate and wound around a chain drum at the entrance to the recess. The chains were rigidly attached to the gate, and this mode of fastening was found to give much trouble. If a gate struck a submerged snag or rock on the track, it stopped moving instantly, and something broke before the engine could be stopped (Sibert 1908:1192).

After being in use for twelve years, the original wooden gates at Davis Island were replaced by steel gates. These gates had a Pratt type top truss, flanged wheels, and lateral movement of the gate was provided by hanging the framework upon each axle by eye-bar hangers. The new gates used rectangular valves instead of the circular butterfly valves of the original gates (Sibert 1908:1192-93).

Other early Ohio River locks used gates similar to the steel gates of Davis Island. The water screen consisted of horizontal white oak planks bolted to vertical, 15-in I-beams, which rested at top and bottom against horizontal members. Gate valves were placed in the bottom of the gate, 18 in each gate. The valves were rectangular, horizontal axis butterfly valves approximately 3 feet by 4 feet in size. These valves were operated by hand from the top of the gate using racks and pinions. These gate valves functioned only when the wall valves were not operational or for flushing debris out of the lock chamber and tail bay (Sibert 1908:1193).

Corps engineers made improvements to the operating mechanism of later rolling lock gates. The operating chains were 1 ¼ inch crane chains fastened at each end of the gate to a tug-lever arranged with a spring control. This spring control diminished the shock due to starting and stopping the gate (Figure 1-9). To prevent chain breakage, the connections to the tug-levers were made by shackles and pins of a size that the pins would break before the chain. Power for the gates was provided by a horizontal, double cylinder, 10 by 12 inch engine operated by compressed air (Sibert 1908:1193-1194). Horizontally pivoting valves were placed in the lower sector of the lock gates (Figure 1-10).

Because drift collected in the gate recesses at Davis Island, a drift chute was installed in Locks 2 through 6. The drift chute consisted of a tunnel that ran from the rear of the upper gate recess down past the rear of the lower gate recess and emptied into the tail-bay of the lock. The entrances to the drift chutes were provided with movable doors (Sibert 1908:1195).

All Ohio River locks built before 1914 had rolling gates housed in recesses in the lock landwall (Plates 1-16, 1-17, 1-18 and 1-19). According to Leland Johnson, these rolling gates worked well on the upper Ohio River where the riverbed consisted primarily of coarse gravel and floods were of relatively short duration. The chief difficulties with these gates were broken wheels or worn out tracks. Below Huntington, the Merrill gate recesses filled with sand and mud from the soft, shifting banks after every floods. Because of this difficulty, the rolling gates were replaced in locks begun after 1914 with structural-steel, swinging mitering gates (Johnson 1977:130; Kutz 1930:434).

Figure 1-8. Ohio River Lock No. 6. General plan of upper gate (Craighill 1903). From Cartographic Branch, National Archives.

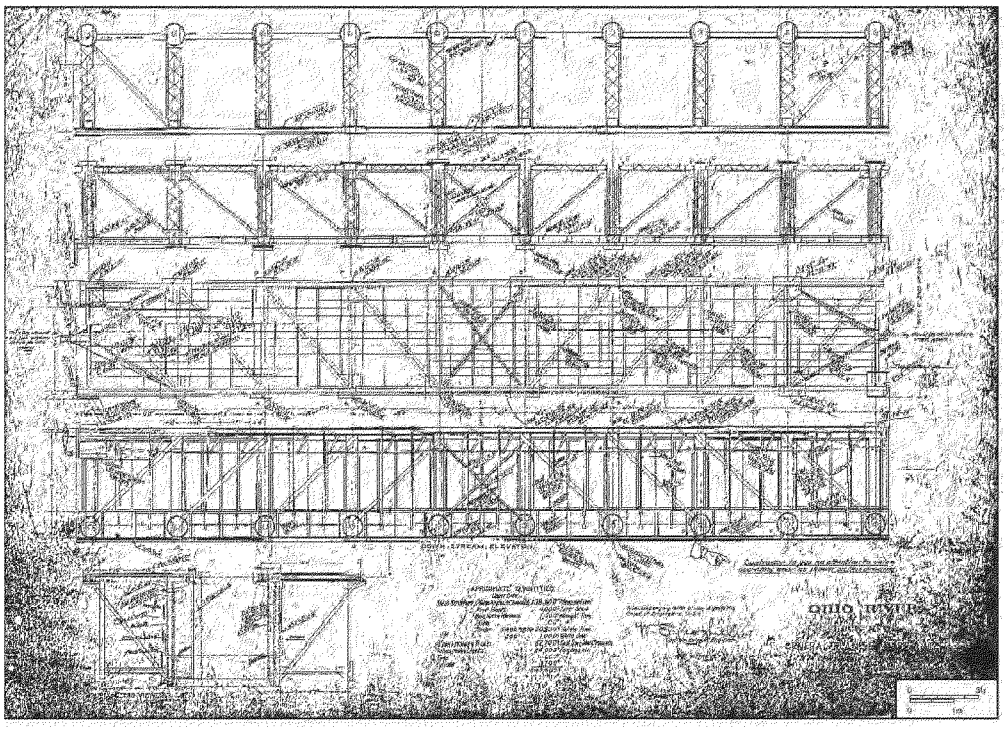


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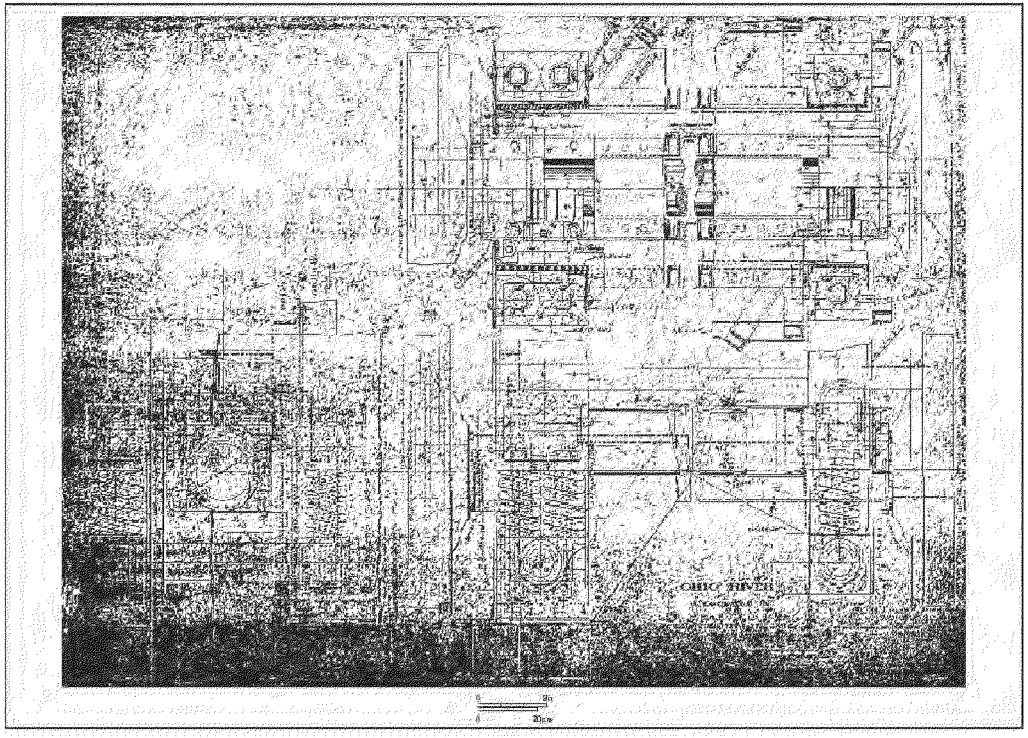
Figure 1-9. Ohio River Lock No. 6. Wheel arrangement for gates (Craighill 1903). From Cartographic Branch, National Archives.



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A typical rolling lock gate on the Ohio River measured about 116 feet in length, 12 feet in width, and 20 to 24 feet in height. The upper gate weighed about 120 tons, while the lower gate weighed about 160 tons. Springs were fitted to the axle bearings and carried the weight of the gate. Posts, horizontals, and bracing carried a system of steel framing. A wooden bulkhead attached to the downstream side of the gate, took the water pressure. A horizontal water seal rail extended along the downstream side of the gate for its entire length, and a vertical water seal was placed on the downstream side of each end of the gate (Hall 1934:25).[1]

As of 1929, the following locks on the Ohio River used miter gates: Emsworth, Deadman Island, #16, #17, #21, #22, #23, #25, #27, #33, #36, #38, #39, #41, #43, #44, #45, #46, #47, #49, #50, #51, #52, #53. The following locks on the Ohio River used rolling gates: #5, #6, #7, #8, #9, #10, #11, #12, #13, #14, #15, #18, #19, #20, #24, #26, #28, #29, #30, #31, #32, #34, #35, #37, and #48 (Jones 1929). Rolling gates were also installed on the Bruges, Belgium Ship Canal; at the tidal lock on the Charles River in Boston; and on the Nile River, among other waterways (Thomas and Watt 1913:II:453).

Most rolling gates on the Ohio River remained in satisfactory working order until the lock was closed. In one case, at Lock 37, it was necessary to replace the lock gates due to extensive rust and corrosion (Hall 1934). In other cases, such as Lock No. 4, the rolling gate tracks were found to be badly worn and bent and needed to be replaced. In the case of Lock 4, the track was replaced by one constructed of high carbon steel with rivets countersunk an extra ½ inch over standard (Bain 1929).

Miter Gates

More navigation locks in the United States use miter gates than any other gate type. Each gate consists of two leaves of equal size and is hinged at the top by means of a gudgeon pin, a fixed part of the leaf which seats in a gudgeon or eye connected to the wall by adjustable anchorage bars. Directly below the gudgeon pin, on the bottom of the gate leaf, is a socket called the pintle shoe. This shoe bears upon and semi-encloses the pintle, a carefully finished hemispherical member fixed to a base on the shelf in the lock wall. The gate is suspended in position by the gudgeon and the pintle, and pivots about these points when in motion. When the miter gate is opened the leaves are swung into recesses in the walls so that the downstream faces are flush with the wall surfaces (Engineer School 1940:57).

The miter gates used at Ohio River locks, operated by a hydraulic oil cylinder and piston, were designed in the Louisville District in 1913. To span the wide openings of Ohio River lock chambers, the engineers combined an interior bracing frame, surrounded by steel-skin plates, with the traditional flat leaf miter gates form. These gates opened and closed with a single stroke of the piston, required less time and less power to operate than the rolling gates (Johnson 1975:185; O'Brien et al. 1992:87).

[1] The Hall article cited in the references describes the replacement of the lock gates at Lock 37 on the Ohio River.

Plate 1-16. Upper rolling gate recess. Lock 12. Wheeling, West Virginia. September 19, 1910 (Stimson 1912).

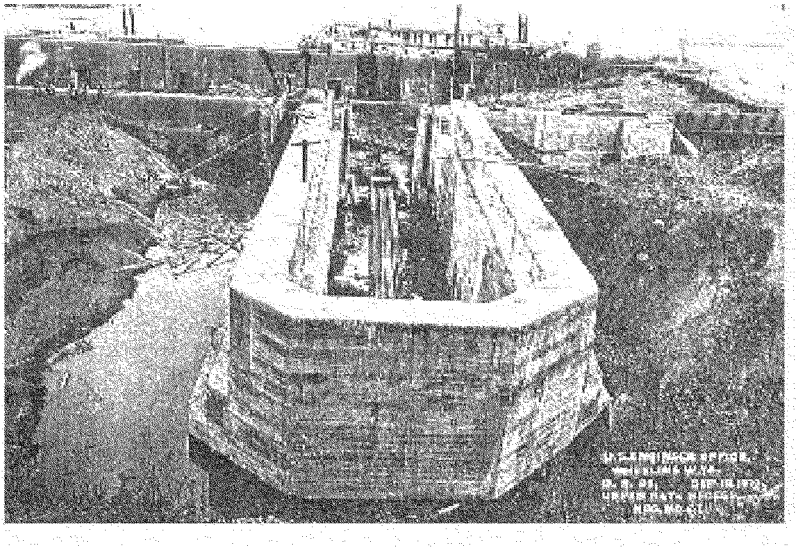

Plate 1-17. Lower rolling lock gate. Lock 12. Wheeling, West Virginia. October 31, 1908 (Stimson 1912).

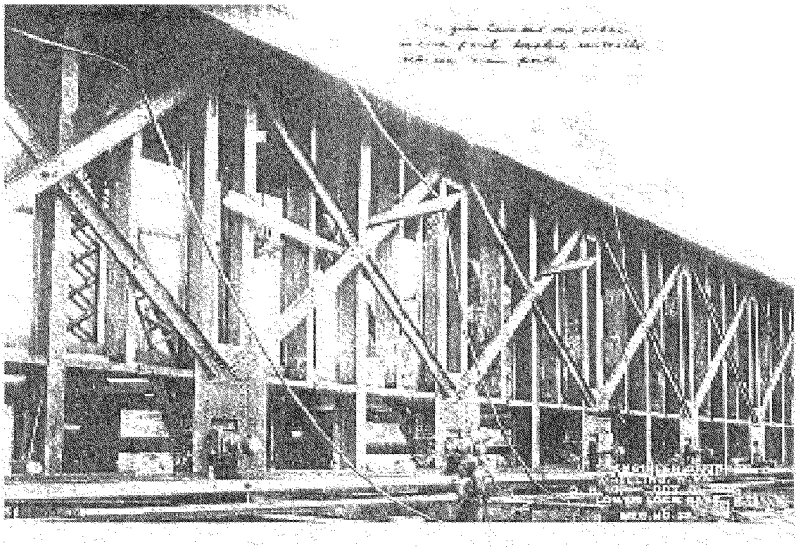

Plate 1-18. Ohio River Lock #48. General view showing downstream side of lower rolling gate from land end. November 7, 1945. From the files of the Louisville District, U.S. Army Corps of Engineers.

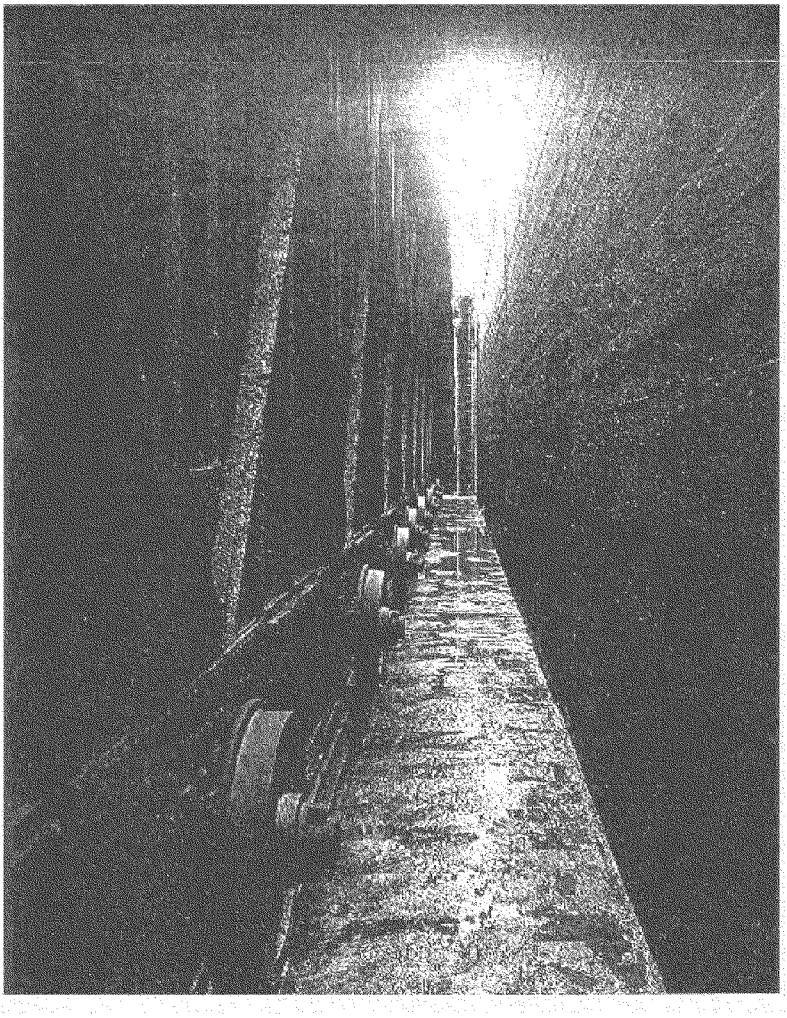

Plate 1-19. Ohio River Lock #48. Repairs to rolling lock gate. General view at lower gate, looking landward; gate in recess. June 18, 1938. From the files of the Louisville District, U.S. Army Corps of Engineers.

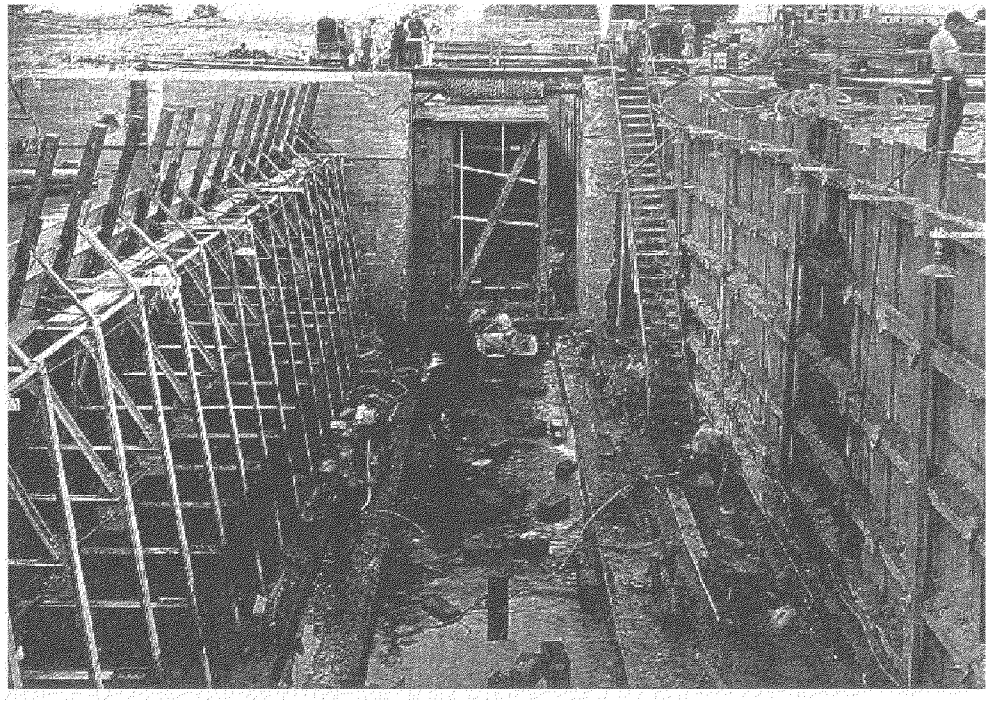

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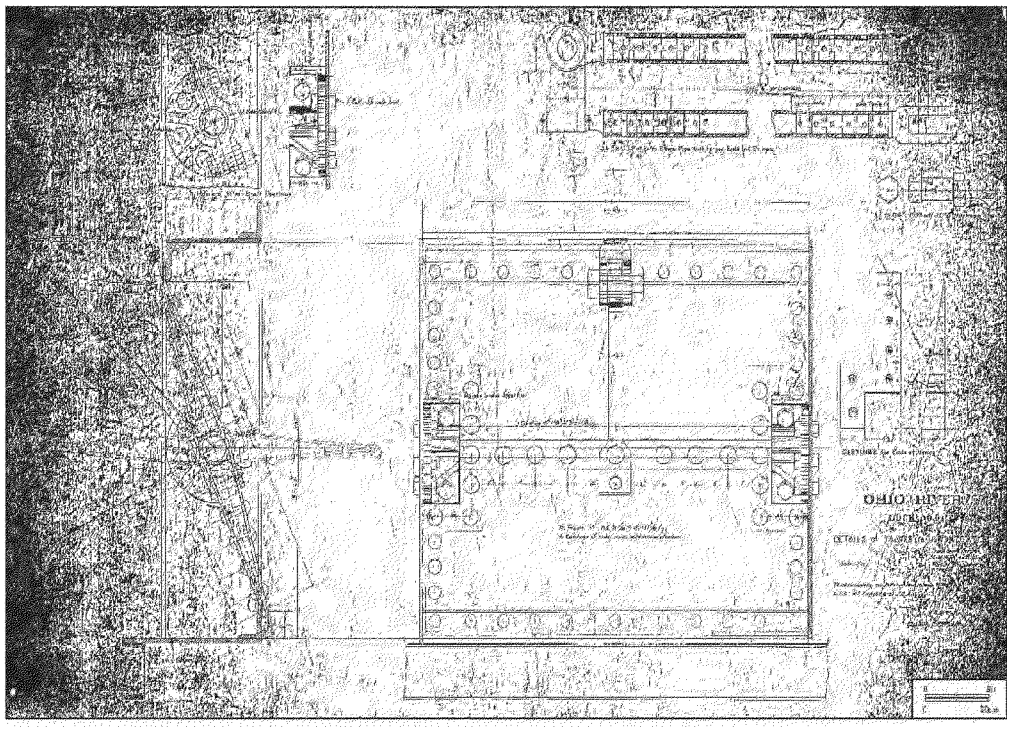
Figure 1-10. Ohio River Lock No. 6. Details of valves for lock gates (Craighill 1902). From Cartographic Branch, National Archives.



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Miter gates are either horizontally or vertically framed, distinguished by whether the main load-supporting members run horizontally or vertically. Engineer Malcolm Elliott described the differences between the two gate types:

> A horizontally framed gate is one which resists the water pressure by means of a series of *horizontal* members more or less uniformly distributed from the bottom of the gate to the top. Each horizontal member receives the load on its own portion of the gate and is supported at one end by a corresponding member of the opposite gate leaf and at the other end by the lock wall.
>
> In [the vertical lock gate] the loads are carried by a series of *vertical* girders more or less uniformly distributed throughout the length of the gate. These vertical girders are supported at the bottom by a sill anchored into the floor of the lock, and at the top by a horizontal member which is in turn supported in the same way as are the horizontal members of a horizontally framed gate (Elliott 1915:405).

Vertical framed miter gates were initially thought to be better suited to the wide dimensions of Ohio River locks. In 1915, it was reported that the vertical frame mitering type had been approved for all Ohio River locks that were to be built in the future (Elliott 1915:415). High narrow gates are generally best framed horizontally while wide, low gates are best framed vertically (Engineer School 1940:58-59).

For example, the original smaller lock gates at Deadman Island Lock and Dam [present Dashields] were horizontally framed. The horizontal members were 24-inch, 80-pound I-beams framed to vertical quoin and miter beams of similar section. A diagonal eyebar extended from the upper end of the quoin beam to the lower end of the miter beam. The gates for the larger lock were vertically framed. Two vertical 48-inch quoin and miter girders divided the gate into three sections, each of which was strengthened by a pair of diagonal tension bars and three additional vertical 24-inch I-beams at 4 feet 10 inches, center to center spacing (Casey 1929:445).

The present miter gates on the Ohio River are all similar. The gates are of welded steel construction and the skin plate, girders, and framing are of structural steel with the eye-bars for the diagonals of high strength steel. The skin plate is on the upstream side of the gate, while the adjustable eye-bar diagonals are on the downstream side of the gate (USACE-Huntington 1971:3).

Modern Ohio River miter gates are operated by struts. The struts are connected to the top girder of the gate upstream from the pintle, pushing the gates closed and pulling them open. Ohio River miter gates are operated using the Ohio River design of strut, sector arm and sector (Figure 1-11). The angle of travel of the sector in the Ohio River type is less than 180 degrees, and the line of the strut does not quite pass through the axis of the sector at either limiting position (Engineer School 1940:391-392). An electric-hydraulic system provides the power necessary for gate operation.

Culvert System

Each of the early numbered locks was equipped with a conduit that ran across under the bottom of the lock from the bottom of a well in the power house to the bottom of another well in the river wall. The pipes that supplied pressure for working the river wall valves and beartrap gates were located in these conduits (Sibert 1908:1197). Ports for emptying and filling the original numbered

locks were located in the river wall. A total of seventeen openings were placed above the dam for filling, and the same number below for emptying (Kutz 1930:434). This type of culvert system was used to fill and empty most late nineteenth and early twentieth century locks of the United States including those constructed on the Monongahela River and the Cumberland River in Tennessee and Kentucky (Griffin 1950:833).

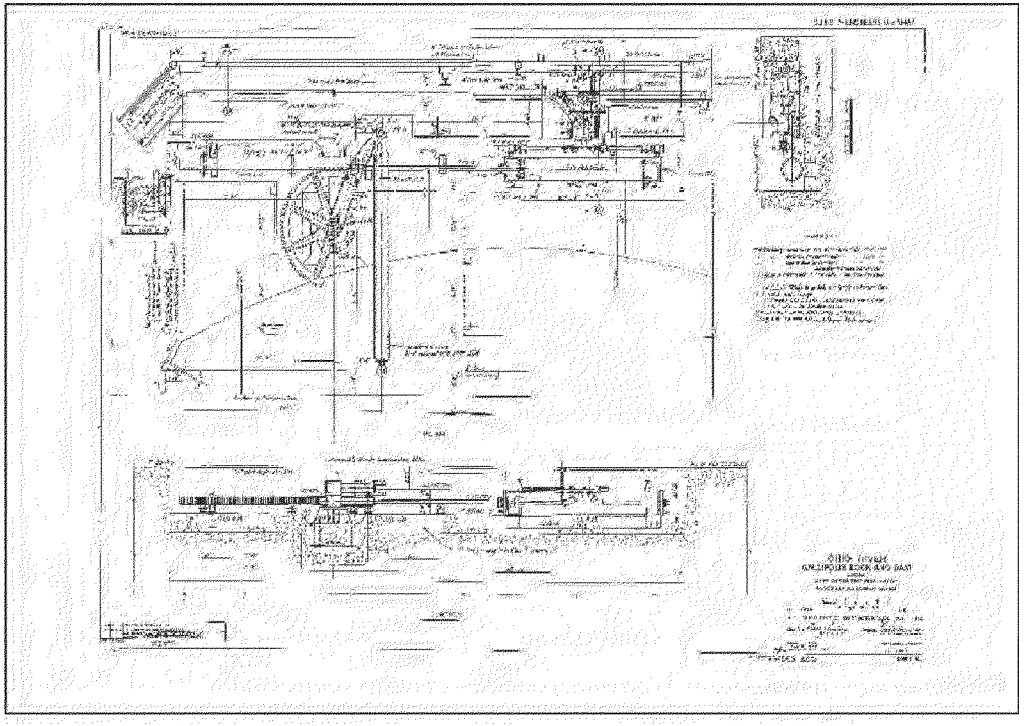
This early culvert system was described by Thomas and Watt in their landmark study of river navigation improvements:

> ....the transverse culvert has been applied to the locks of the Ohio River and to occasional ones elsewhere. On the Ohio locks a series of openings (16 for filling and 16 for emptying) is placed in the river wall..., above and below the dam. These are closed by cast-iron butterfly valves, 4 ½ feet in diameter, moving on vertical shafts. The water enters the chamber directly from the river through one set of valves placed upstream of the dam and empties directly into the river through a second set of valves placed downstream of the dam. The method has worked very satisfactorily, but it was found in the earlier examples that where the filling valves were some distance downstream of the upper end of the wall, the slope of the river in moderate stages resulted in a level in the chamber slightly lower than that above the gates, and the head had to be equalized by using valves in the gates before they could be operated easily. There is some tendency also, as with valves in the gates, to an uneven flow of water in filling the chambers (Thomas and Watt 1913:II:492-493).

A. Frederick Griffin described the use of the early culvert system in the first generation of Ohio River locks:

> Many of the locks on the Ohio River are of low lift and are filled or emptied through a series of ports in the river lock wall controlled by butterfly valves....The filling valves, in the upstream section of the wall, discharge directly from the upper pool into the lock chamber. The emptying valves, in the downstream section of the same wall, discharge directly into the lower pool. Filling time averages from about 5 min to 8 min, and emptying requires from 4 min to 6 min, depending on the head.
>
> During the filling operation, flow through the filling ports creates a turbulent eddy in the lock chamber with a downstream flow along the lock wall. Somewhat similar currents are experienced during emptying operations....The action of the currents described is ordinarily controlled by judicious opening of the filling and emptying valves.... (Griffin 1950:833-834).

Figure 1-11. Gallipolis Locks and Dam. Locks. Gate operating machinery assembly at lower gates (U.S. Engineer Office, Huntington 1933). (From USACE-Huntington 1970).



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In the next generation of locks, the individual filling and emptying culverts for each valve were replaced by culverts that ran the length of the lock walls. This type of system was used in locks on the Monongahela River, the Allegheny River, the Kanawha River, the Tennessee River, the Upper Mississippi River, the Illinois Waterway, the New York State Barge Canal, the Intracoastal Waterway, and the Welland Canal (Griffin 1950:835). The Deadman Island (Dashields) Locks use this longitudinal culvert system for filling and emptying the chambers. In his article on construction of the locks and dam, Hugh J. Casey described the features of this system:

> The culverts for the operation of the 110-foot lock extend through the land and middle walls while that for operation of the small lock extends through the river wall. Through the walls at the head of each culvert is a series of screened openings 5 feet square, which taper to 4 feet square as they enter the culvert. The culvert is of sufficient size and structural shape to carry the water through the wall. A large butterfly valve near the head of the culvert below the intakes controls the inflow. A series of similar 3- by 4-foot openings, tapering out to 4 by 5 feet branch off from this culvert into the lock chamber. The culvert diminishes in size toward the center of the chamber as its flow capacity decreases. As the culvert approaches the lower end of the lock wall, it tapers out again to the same size it had at the upper entrance. Here it has a similar butterfly valve and a series of openings branching out from it into the lower lock approaches. The openings are all below draft line…This system will fill or empty the lock in five and one-half minutes (Casey 1929:446).

A similar culvert system was used in the auxiliary chamber at McAlpine Lock. An 8 by 10 foot tunnel extends the length of each wall with four intake ports measuring 4 feet by 6 feet located in the face of the upper miter gate recesses and four discharge ports measuring 4 feet by 6 feet located immediately below the lower miter gate (Rhett 1971).

The Gallipolis locks have culverts in the land, middle and river walls, each measuring 12 feet 6 inches square in section. Three intake ports, each measuring 8 feet by 10 feet in section provide water for the culverts. The water is discharged in discharge ports measuring with 5 feet by 6 feet or 7 feet by 6 feet in section.

Because of the increased size of locks installed during the post-World War II modernization program on the Ohio, more efficient means of filling and emptying the chambers were needed. The emptying system using ports in the lock walls would have created intolerable turbulence and excessive hawser stresses for tows tied in the lock chambers because of the much higher rates of filling and emptying. To prevent these problems, a new system was developed with parallel lateral culverts across the lock floor with ports in the sides of the laterals spaced alternately in adjacent laterals. This system, developed on the Ohio River, was, at the time of its introduction, unique in the United States. Bruce et al. described it in a 1957 article on the Ohio River navigation system:

> Main lock design for the new high-lift locks on the Ohio River locates one group of laterals in the center of the upstream half of the lock. This group is fed by a culvert in the upper half of the river wall. The arrangement permits the discharge outlet for the upper group of laterals to be located near the center of the lock and shortens the length of the culvert which would otherwise be required in the river wall. A second group of laterals is located in the center of the downstream half of the main lock. This group is fed by a culvert located in the intermediate wall

> between the main and auxiliary locks. The discharge outlet for the lower group is carried from the lower end of the culvert in the intermediate wall across the bottom of the main lock and through the river wall to discharge in the river. The idea for the design of the filling and emptying system, which splits the laterals into two groups, is of French origin, but the details have been worked out by exhaustive model tests made for the high-lift Ohio River locks (Bruce et al. 1957:1239-9-10).

Post World War II locks on the Ohio River use larger longitudinal culverts in their filling and emptying system. For example, at the Captain Anthony Meldahl Locks, the 1,200 foot lock fills and emptied through 16 foot wide and 18 foot high culverts in the river and middle walls, and the 600 foot lock is filled and emptied through a single 16 foot wide and 18 foot high culvert in the land wall. Intake manifolds are placed in each lock wall. (USACE-Huntington 1969:4).

Before construction, the culvert system used in the New Cumberland locks was tested using a 1:25 scale model at the Hydraulic Laboratory of the Corps of Engineers in Iowa City. A. Frederick Griffin described the proposed culvert layout and the results of these tests:

> Longitudinal culverts in the river and middle walls connected to intake manifolds in the sides of the approach walls, to lock-chamber ports in the sides of the walls, and to outlet manifolds discharging into the tail bay below the lower miter gates are proposed for the main lock. The auxiliary lock is filled and emptied by an intake manifold, a longitudinal culvert, and a discharge manifold in the land wall, the longitudinal culvert being connected to laterals with side ports in the chamber floor. Tests on the main lock have shown that modifying the lock-chamber ports so that the jets from the ports strike the floor of the lock chamber at the base of the opposite wall, instead of at the midpoint of the floor, results in a reduction of hawser stresses by an average of 50%. With an assumed 2-min time of culvert-valve operation, satisfactory filling in about 8 min and emptying in about 8.4 min was obtained. It was also found that reducing the inside area of the laterals in the auxiliary lock chamber, in steps from the first port to the end, would result in a more equal distribution of flow during filling operations (Griffin 1950:850).

In the Racine locks, the large lock is filled and emptied through culverts in the river and middle walls, while the small lock is filled and emptied through a culvert in the land wall. Intake manifolds are provided in each lock wall upstream from the emergency bulkhead sill. The main lock chamber has a series of wall ports in each lock wall, opening into the lock chamber from the wall culverts at an elevation a minimum of 28 feet below the normal lower pool. The lock culverts are emptied through outlet structures extending outside the river wall to divert the flow outside of the lower lock approaches.

At Racine, room was not available in the middle wall to accommodate two culverts and the necessary valves. Therefore, a system of bottom laterals was adopted for the filling and emptying system in the auxiliary lock. The system of bottom laterals, having openings along both sides and connecting with the culvert in the land wall only, extends across the floor of the lock chamber to distribute the flows and reduce turbulence. The Racine system is based upon model studies for Cannelton Locks (USACE-Huntington 1971:4).

The Belleville locks culvert system was based on model studies performed for the Greenup and Markland locks. The main lock is filled and emptied through 15 by 16 foot culverts in the river

and intermediate walls, and the auxiliary lock is filled and emptied through a 15 by 16 foot culvert in the land wall. Laterals, having ports on both sides and connected at one end to a wall culvert extending across the lock chamber, were adopted for dispersing flows and reducing turbulence in the chambers. Discharge outlets are used for each lock culvert to divert the entire flow outside of the lock approaches (USACE-Huntington-Belleville:5).

At Smithland locks, the ports are approximately centered in each lock chamber. These ports, each of which measures 2.75 feet wide and 3.50 feet high at the throat, are spaced on 28-foot centers. Ports in the opposing walls are staggered so that the issuing jets will not interfere with one another. These ports extend over 50 percent of the lock chamber and have triangular deflectors installed in front of the upstream one-third of the ports. These deflectors measuring 12 feet by 12 feet by 3.5 feet high are installed to reduce the high upstream longitudinal hawser stresses which occur during the filling operations. Each sidewall port manifold contains 25 ports (USACE-Louisville-Smithland E-1-2).

Hydraulic System and Machinery Operation

Typically, in modern locks, the lock's machinery is actuated by hydraulic pressure supplied from a pumping station within the operation building. For example, at Meldahl Locks, the pumping equipment consists of three main pumps and a smaller pressure-holding pump, powered by electric motors. Related equipment includes an oil storage tank, oil filters, and pressure control devices (USACE-Huntington 1969:7).

At Racine and other recently constructed locks, the hydraulic piping circuits for the lock gate operating machinery and the lock chamber filling and emptying machinery are closed pressure systems where a constant operating pressure is maintained. Separate pipe systems are provided for each lock, with interconnection at the pumps in the operation building (USACE-Huntington 1971:2).

The New Cumberland Locks are typical of modern Ohio River locks in the operation of its gates and filling and emptying valves. The main elements comprising the gate operating machinery consist of a cylinder, piston and piston rod, rack, sector gear, sector arm, and strut. The piston rod is in the extended position when the gate is closed. The cylinder is located on the downstream side of the sector gear with the rack, gear and strut in the same plane. The strut incorporates a shock absorber assembly containing a nest of ring springs to protect the operating machinery from instantaneous transmission of shock loads into the machinery (USACE-Pittsburgh 1976:5).

The main elements comprising the culvert valve operating machinery consists of a cylinder, a piston, piston rod, cross-head, cross-head guides, connecting rod, rocker and strut. The piston rod is connected to the cross head which is pin connected to one end of the connecting rod. The other end of the connecting rod is pin connected to the upper arm of the rocker and the strut is pin connected to the lower arm of the rocker. The bottom end of the strut is attached to the pickup connection on the center of the valve by means of a pin. The strut incorporates a spring assembly to insure positive seating of the culvert valve in the closed position (USACE-Pittsburgh 1976:8).

Valves

Ohio River locks have used three types of valves: butterfly, tainter, and Stoney [and cylindrical].

Butterfly valves are installed to swing on either the horizontal or vertical axis (Plate 20; Figure

12). The axial structural member is called the stem. The blade of the valve is attached to and supported by the stem. A vertical stem also usually serves as the means of opening and closing the valve, whereas a strut generally operates the horizontal stem type. The valve blades may be either circular or rectangular (Engineer School 1940:369).

Vertical butterfly valves are also used at only one lock complex in the Pittsburgh District, Emsworth. The main lock is filled by 16 valves located in the upper end of the middle wall and emptied by 16 similar valves which pass water through the lower end of the wall and under the riverward chamber into the river below the dam. The auxiliary lock is controlled by six filling and six emptying valves, located in the riverward wall.

A tainter valve is a steel plate sector of a cylinder, supported by ribs which are in turn supported by beams which carry the load to radial struts at either end (Figure 1-13). The end struts bear upon and revolve about trunnions which are at the axis of the skin plate cylinder. The first tainter valves used on the Ohio River were hydraulic operated by a cable and pulley mechanism (Figure 1-14).

When a tainter valve is installed with the trunnions upstream from the face, it is called a reverse tainter valve (Figure 1-15). Early Ohio River tainter valves were operated using a cable and cylinder mechanism. Tainter valves are either horizontally or vertically framed. Test installations of vertically framed valves indicated that this configuration reduced the variation in hydraulic forces acting on the valve (Figure 1-16).

The Stoney gate valve was developed by the Irish engineer Francis G.G. Stoney (1837-1897) who first employed it in 1875 (WVU n.d.:II:9). The Stoney gate valve resembles a thin flat box, which is raised and lowered vertically to and from its sealed closed position (Figure 1-17). The downstream side rests on a rolling train running on a metal frame set in the masonry, or fixed rollers on the gate rest directly on the supporting track frame. The valve moves in a recess in the culvert side walls, and the gate and roller train are counterweighted (Engineer School 1940:372). The only lock chamber on the Ohio River that presently uses Stoney valves is the 360 foot auxiliary chamber at McAlpine Locks. The first use of the valve in the United States was at Lock 9 on the Monongahela River. Stoney valves are presently used for empty and fill valves at Winfield, Marmet and London locks on the Kanawha River.

The numbered locks of the Ohio River all used butterfly valves. These valves were mounted on vertical axes that extended to a pit in the top of the wall in which the operating mechanism was located. C.I. Grimm, an engineer with the Cincinnati Corps office described the operation of the valves:

> The valve is rotated through an angle of approximately 75 degrees by means of a sector at the top of the stem, engaged by a rack which is moved forward or back by the piston of a small hydraulic cylinder jack. These jacks are connected to common pipe lines, the pressure in which is reversed and regulated from a central point (Grimm 1930:52).

Plate 1-20. Emsworth Locks and Dam. Large lock. Butterfly emptying valve (U.S. Engineer Office, Pittsburgh 1945). From the files of the Pittsburgh District, U.S. Army Corps of Engineers.

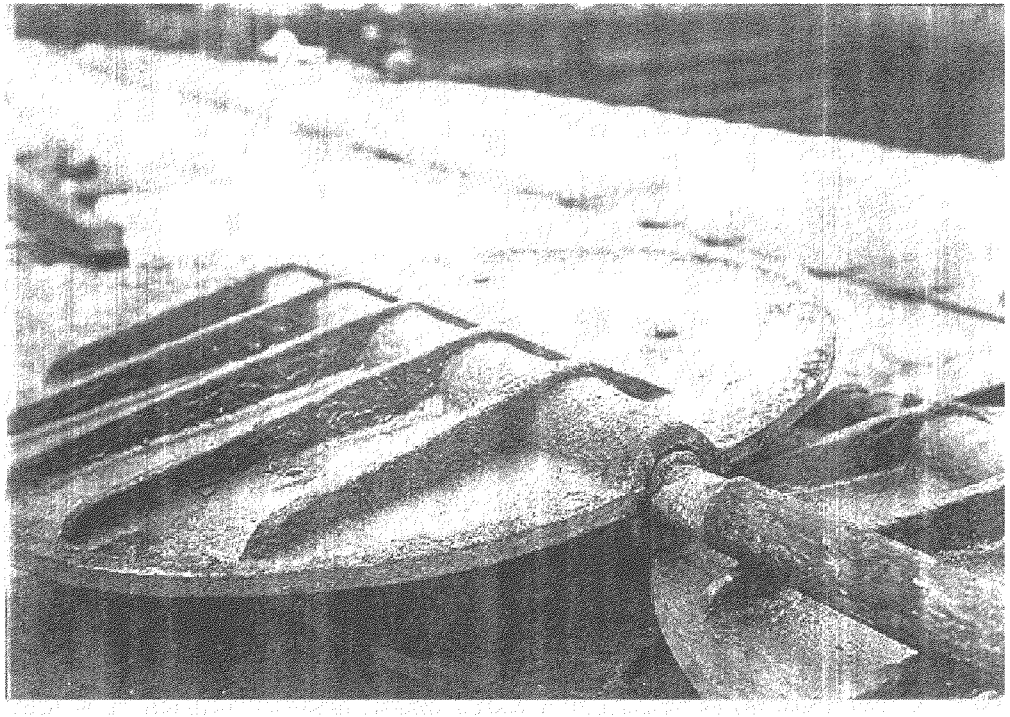

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Plate 1-21. Dashields Lock. New emptying valve (U.S. Engineer Office, Pittsburgh 1933). From the files of the Pittsburgh District, U.S. Army Corps of Engineers.

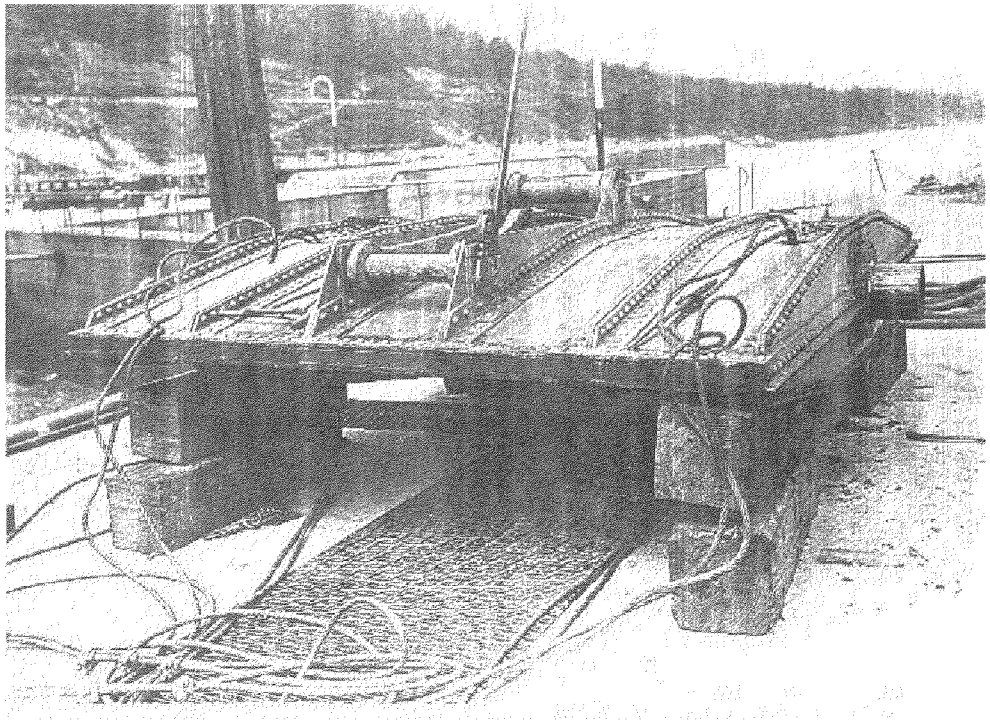

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Figure 1-12. Emsworth Lock and Dam. Vertical butterfly valves and frames (U.S. Engineer Office Central Division 1919). From Cartographic Branch, National Archives.

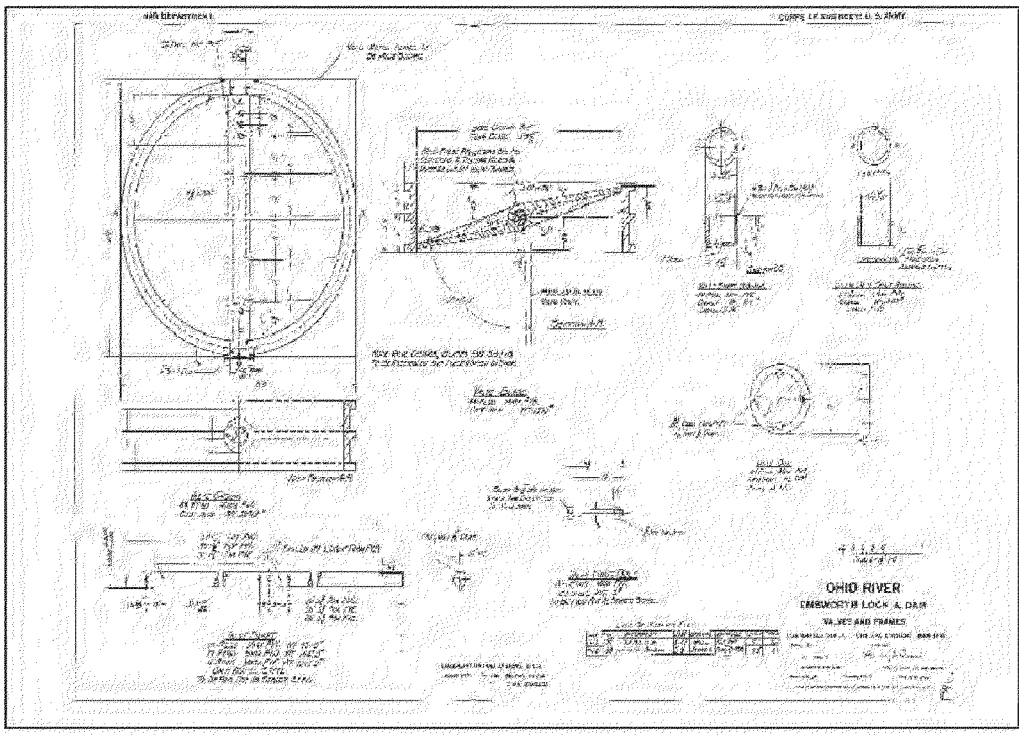

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Figure 1-13. Gallipolis Locks and Dam. Tainter valves. General drawing (U.S. Engineer Office, Huntington 1933). (From USACE-Huntington 1970).

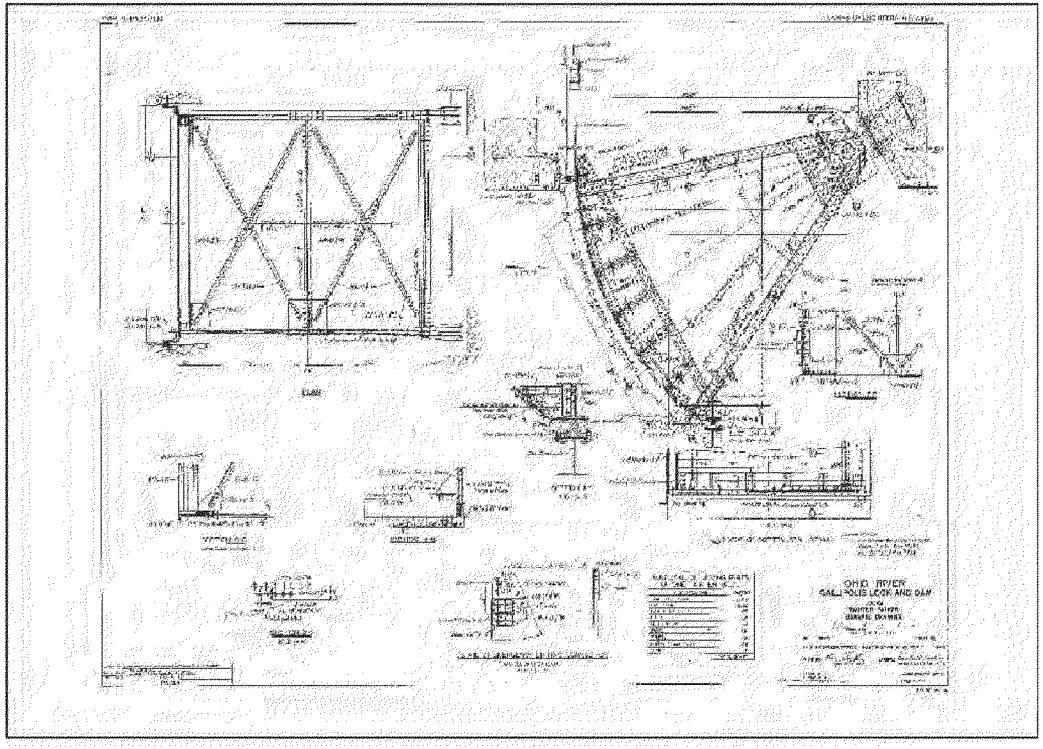

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Figure 1-14. Gallipolis Locks and Dam. Tainter valve operating machinery (U.S. Engineer Office, Huntington 1938). (From USACE-Huntington 1970).

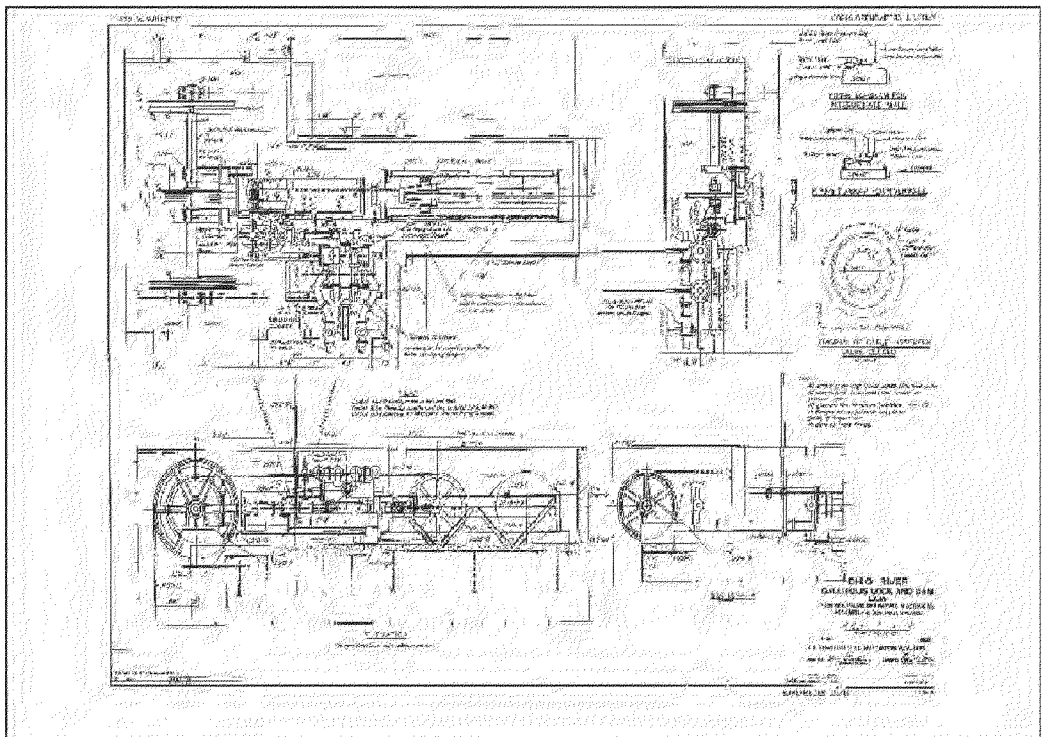

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Figure 1-15. Winfield Lock and Dam. Reverse tainter valve and wire rope mechanism (USACE-Huntington n.d.).

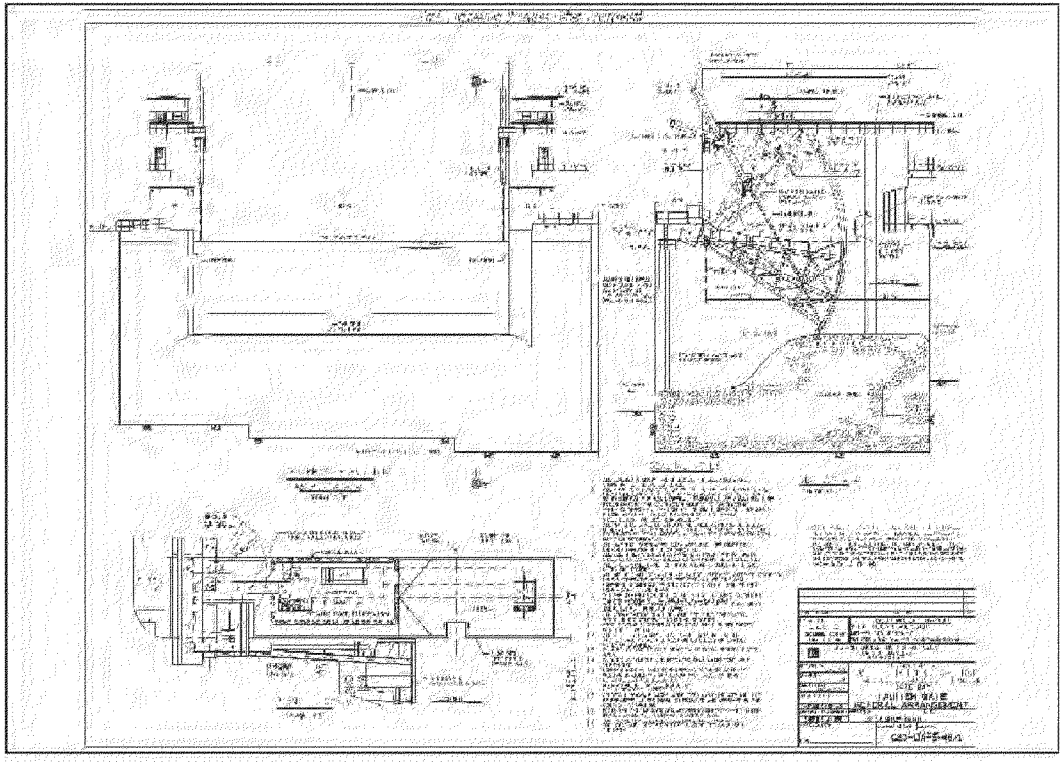

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Figure 1-16. Belleville Locks and Dam. Locks. Culvert valve details showing vertical framing of valve (USACE-Huntington n.d.).

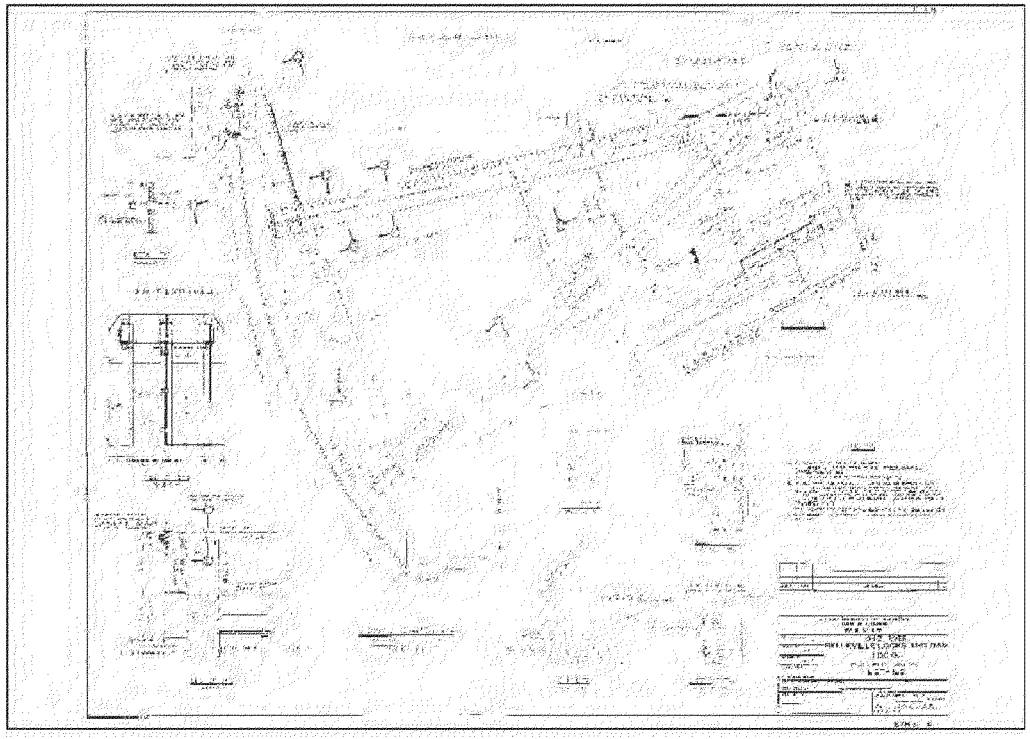
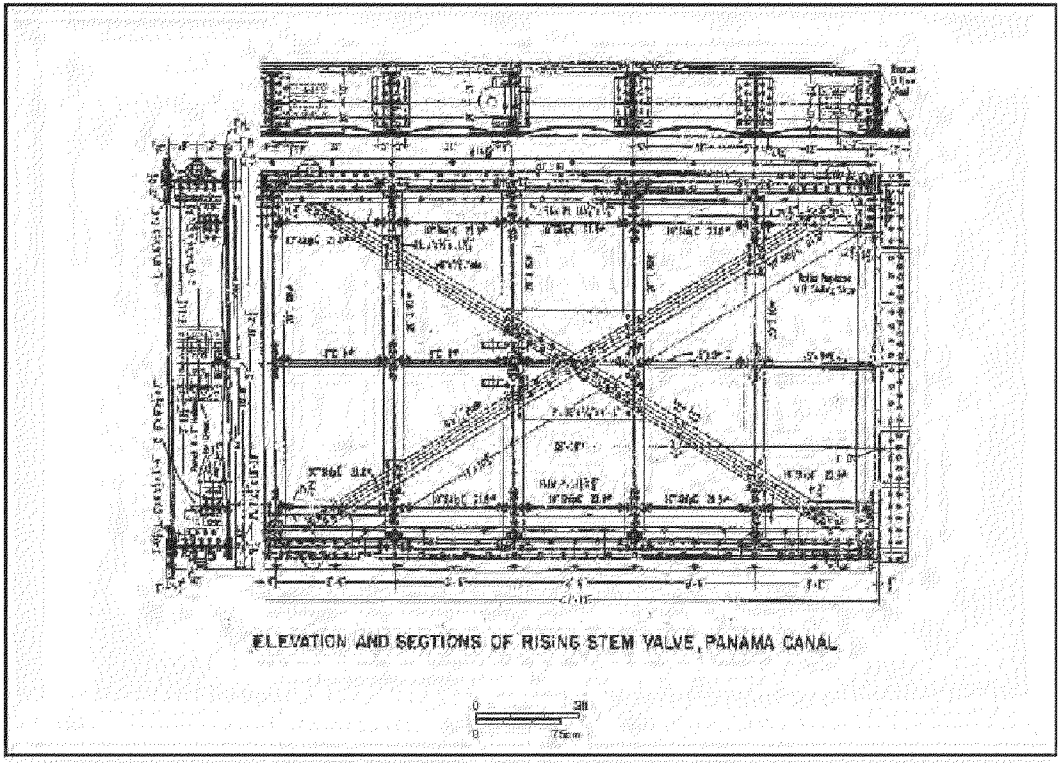


Figure 1-17. Elevation and sections of Stoney valve (Engineer School 1940).



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At Davis Island, the lock was filled by seven, circular butterfly valves, 4 ½ feet in diameter, in the river wall with the same number in the downstream wall of the upper gate recess. The lock was emptied by seven valves of the same kind and size in the downstream wall of the lower gate recess. The water was discharged into a large conduit that emptied into the tail bay. Gate valves were also used (Sibert 1908:1198). A hydraulic jack connected to a rack and sector gear operated the wall valves (Figure 1-18).

The valves of the subsequent early locks were placed in the river wall of the lock, those above the dam for filling the lock chamber, and those below the dam for emptying it (Figure 1-19). All were circular butterfly valves, of cast iron, 4 ½ feet in diameter (Sibert 1908:1198). A shaft extended from the valve to the top of the wall, and a small compressed air engine or "jack" operated each shaft. The 16 jacks were operated simultaneously (Anonymous 1909b:236; Figure 1-20). Butterfly valves were also employed in the St. Mary's Falls Canal lock in Michigan, and on the Monongahela River (ASCE 1930).

Deadman Island (present Dashields), one of the first of the new generation of locks on the Ohio River, employed structural steel butterfly valves operating on a horizontal axis (Plate 21). These valves operate on cast steel axles rotating on phosphor bronze removable bearings. The smaller chamber culverts uses 10 by 12 foot valves, identical to those installed in locks 6, 7 and 8 on the Monongahela River. The larger chamber uses eight foot by ten foot butterfly valves (Casey 1929:446). These valves are hydraulically operated by a cylinder, cross head and guide, connecting rod, rocker, and strut arrangement (USACE-Pittsburgh 1972a:5).

Montgomery, the second in the new generation of locks on the Ohio River, fills and empties by culverts located in all three walls. The 110 by 600 foot lock fills and empties through culverts in the land and middle wall, and the intake or outlet of water is controlled by four butterfly valves, 13 feet by 14 feet 10 inches, located one at each end wall of the lock. The smaller lock is controlled by a culvert located in the river wall with one butterfly valve, 10 feet by 12 feet, located at each end (Keelor 1935:187). The six butterfly valves are horizontally mounted and hydraulically operated by a cylinder, cross head and guide, connecting rod, rocker, and strut arrangement (USACE-Pittsburgh 1972b:5).

The original Gallipolis Locks used tainter valves for filling and emptying (see Figures 1-13 and 1-14). The complex's first periodic inspection report described features of these valves:

> The tainter valves located in the main culverts to control the water elevations in the lock chamber are framed structures. Each valve has a water-tight skin plate on the upstream side of the valve recess. It is provided with steel-on-steel bottom and wood-on-steel side seals, and with a rubber-on-steel seal at the top. The valves are operated by cables running to hydraulic hoisting machinery; the valve rotates about the center line of the trunnion bearing pins. The trunnion bearings and anchorages are located on the downstream side of the valve recesses, 2 feet above the culvert roofs (USACE-Huntington 1970:21).

Figure 1-18. Davis Island Lock and Dam. Operating machinery of valves in lock walls (reprinted by USACE-Pittsburgh 1985).

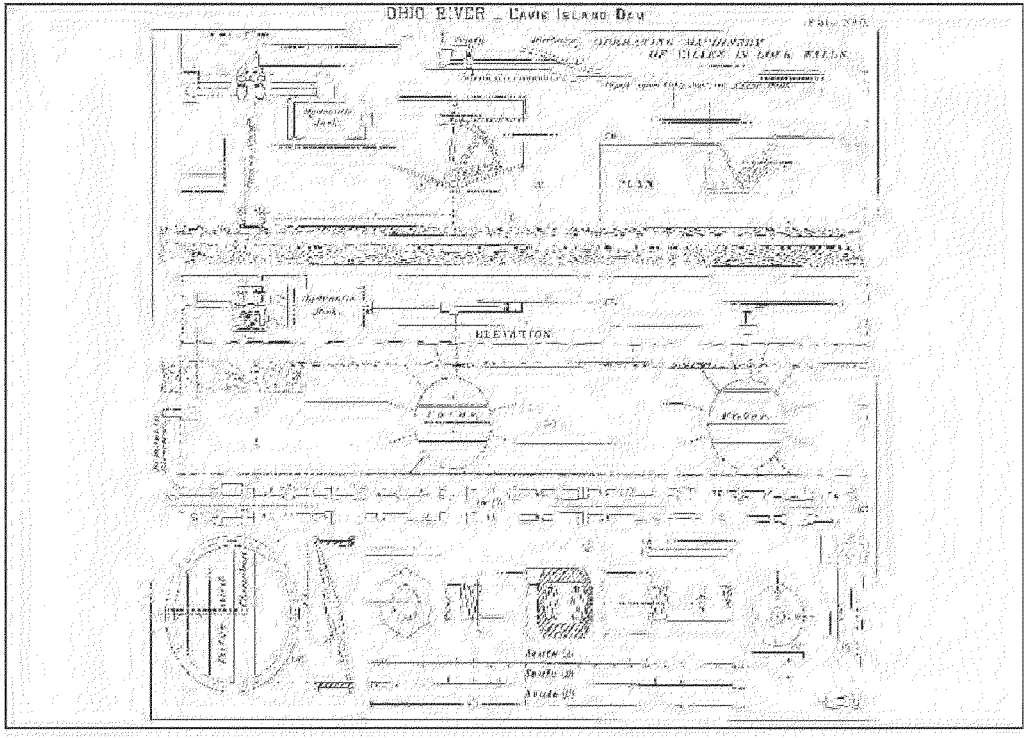

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Figure 1-19. River wall valve with spring debris device used at Dam No. 6, Ohio River (U.S. Engineer Office Pittsburgh n.d.). From Cartographic Branch, National Archives.

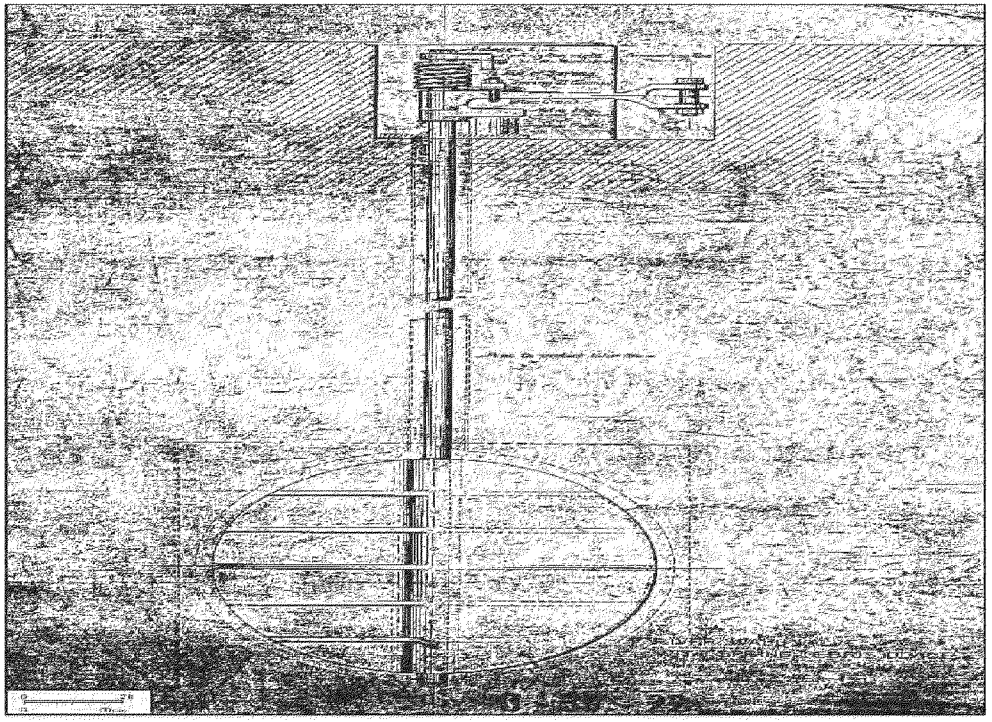

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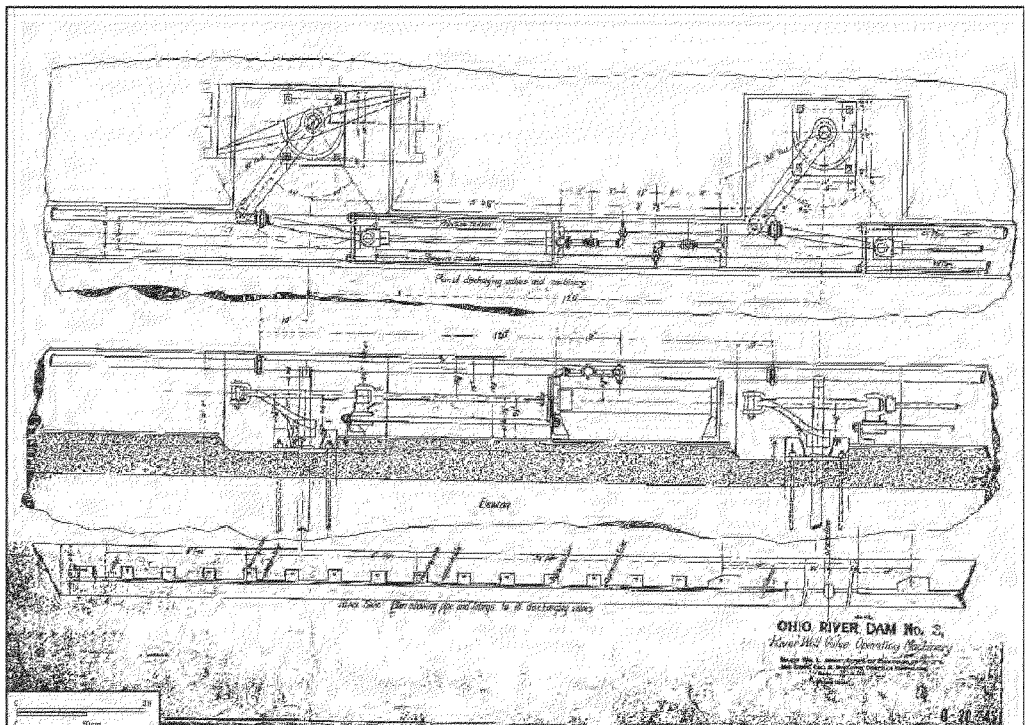
Figure 1-20. Ohio River Dam No. 3. River wall valve operating machinery (Spalding n.d.). From Cartographic Branch, National Archives.



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Montgomery, the second in the new generation of locks on the Ohio River, fills and empties by culverts located in all three walls. The 110 by 600 foot lock fills and empties through culverts in the land and middle wall, and the intake or outlet of water is controlled by four butterfly valves, 13 feet by 14 feet 10 inches, located one at each end wall of the lock. The smaller lock is controlled by a culvert located in the river wall with one butterfly valve, 10 feet by 12 feet, located at each end (Keelor 1935:187). The six butterfly valves are horizontally mounted and hydraulically operated by a cylinder, cross head and guide, connecting rod, rocker, and strut arrangement (USACE-Pittsburgh 1972b:5).

The original Gallipolis Locks used tainter valves for filling and emptying (see Figures 1-13 and 1-14). The complex's first periodic inspection report described features of these valves:

> The tainter valves located in the main culverts to control the water elevations in the lock chamber are framed structures. Each valve has a water-tight skin plate on the upstream side of the valve recess. It is provided with steel-on-steel bottom and wood-on-steel side seals, and with a rubber-on-steel seal at the top. The valves are operated by cables running to hydraulic hoisting machinery; the valve rotates about the center line of the trunnion bearing pins. The trunnion bearings and anchorages are located on the downstream side of the valve recesses, 2 feet above the culvert roofs (USACE-Huntington 1970:21).

Tainter valves became the standard valve type for United States locks beginning in about 1930. Among the first locks to employ tainter valves were Lock No. 2 on the Mississippi River, completed in 1930, and the Welland Ship Canal Locks in Canada, completed in 1933. These early valves were oriented in the manner of a conventional tainter gate, with the trunnions downstream of the skin plate causing the convex surface of the skin plate to face the flow and seal along the upstream end of the valve wall (USACE-ChE 1975:1-3).

However, model tests for the Pickwick Lock on the Tennessee River pointed to a flaw in this design. During the opening period, the pressure gradient immediately downstream of the valve skin plate dropped below the top of the culvert. As a result, large volumes of air were drawn down the valve well and into the culvert. The air formed large pockets in the model culvert which restricted the flow until sufficient pressure was developed to expel the air through the ports or into the downstream bulkhead recess. Air expelled through the ports erupted at the water surface with considerable force causing disturbances that could be hazardous to small craft.

By reversing the tainter valve, placing the trunnions upstream of the skin plate with the convex surface of the skin plate facing downward and sealing against the downstream end of the valve well, air was prevented from entering the culvert at the valve recess. Reverse tainter valves became the standard on Corps of Engineer locks (USACE-ChE 1975:1-3-1-4) (See Figure 1-15).

Reverse tainter valves use one of two types of operating machinery: the strut arm and the wire rope. Strut arm machinery, such as that used at Greenup and Captain Anthony Meldahl consists of a cylinder, piston, piston rod, crosshead, crosshead guides, connecting rod, bell crank, and strut. The piston rod is connected to the crosshead which is pin connected to one end of the connecting rod. The other end of the connecting rod is pin connected to the upper arm of the bell crank and the strut is pin connected to the lower arm of the bell crank. The bell crank is connected to a trunnion which is anchored into the concrete. The bottom end of the strut is pin connected to the center of the valve.

In wire rope operating machinery, the hydraulic cylinder and piston rod is connected to a multiple wire rope single part line which passes over a multiple grooved sheave and is connected to the center of the culvert valve. The sheave is supported on anchorage supported on the concrete. The connection between the piston rod end and the wire rope is a universal joint which incorporates a sliding shoe. The sliding shoe rides on a rail which supports the piston rod and wire rope connection in a horizontal plane. The lock wall masonry is recessed to receive the embedded metal for the cylinder, the sliding shoe rail, and the multiple grooved sheave bearing plate (USACE-Huntington 1962:3-4).

A design memorandum for Belleville Locks cited some of the disadvantages of the strut arm type of machinery:

> 1) The machinery consists of many massive components carrying heavy loads.
> 2) The components are extremely difficult to install in proper alignment.
> 3) Experience at Greenup showed that misalignment of the components causes excessive wear and may entail difficult and expensive maintenance (USACE-Huntington 1962:4).

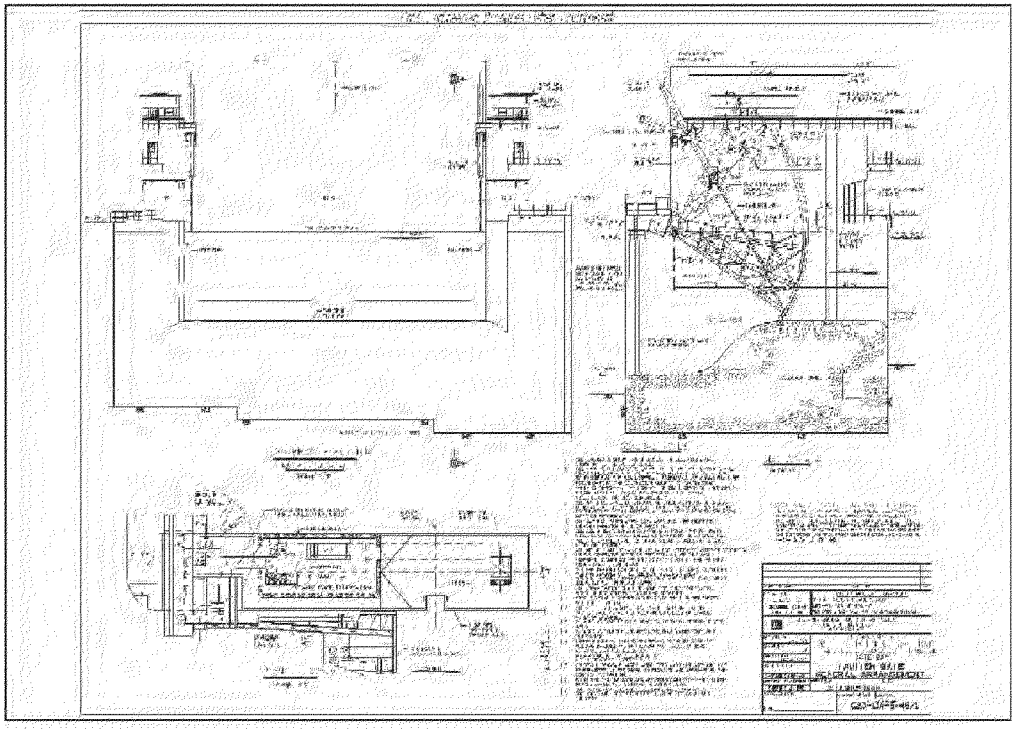
Wire rope operating machinery eliminates the disadvantages of strut arm machinery and is much simpler to fabricate and install. The estimated cost of the machinery was also substantially less. In October 1962, the Corps of Engineers estimated that the cost of wire rope machinery for one valve at $233,000, while the cost of strut arm and bell crank machinery was estimated at $314,000 (USACE-Huntington 1962:10-11). Wire rope operated tainter valves were first successfully used at Gallipolis Lock with negligible wear on the corrosion resistant ropes. This system was subsequently installed at Racine, Willow Island, and R.C. Byrd locks on the Ohio River and Winfield Lock on the Kanawha River (McCoy 2000).

The Meldahl locks employ a typical modern tainter valve installation. All of the valves at the Meldahl locks are identical and have a radius of 26 feet. The valves are larger but similar in design to those used at Lock No. 19 of the Mississippi River. The construction of a typical tainter valve is described in the first periodic maintenance report for Meldahl:

> They are made of welded construction with rolled beams of structural steel, plate material of low alloy steel and the bottom seal edge of corrosion resistant plate. The valve blade is horizontally framed with skin plating on the downstream face. The bottom shape of the valve was designed to provide a narrow bottom edge to improve underflow characteristics and eliminate any tendency of the valve to vibrate. The water load is carried to the trunnion bearings through end frames (USACE-Huntington 1969:5).

The valves have a radius of 26 feet from the center of the trunnion to the inside face of the skin plate. Horizontally framed valves and trunnion mechanism for hoist were used at Greenup and Meldahl locks in the Huntington District. These valves have required more maintenance than the wire rope and vertically framed valve arrangement (McCoy 2000; Figure 1-21).

Figure 1-21. Winfield Dam. Gate bay showing non-submergible tainter gate and hydraulic cylinder hoists (USACE-Huntington n.d.).



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Dams

The original numbered dams on the Ohio River Navigation System consisted of a navigable pass section with a fixed weir and a series of movable weirs used to regulate pool level. By the mid-1930s, the Ohio River navigation system included 48 movable and two fixed dams. The navigable passes of the movable dams ranged in width from 600 to 1,248 feet (USACE-ChE 1958:924).

Movable Dams

Several requirements governed the design of each movable dam on the Ohio River. Captain P.S. Bond of the U.S. Army Corps of Engineers listed these requirements in an article on the improvement of the Ohio River:

1) Its lift should be as great as practicable, since high lifts would decrease the first cost of the system because of the small number of dams required.
2) It should be capable of being quickly and easily raised in a considerable depth of water without a chance of failure.
3) It should be capable of being very rapidly lowered without chance of failure.
4) The entire dam should be down when water is released.
5) The parts should be very strong, so that they will not readily be injured by boats, ice, etc.
6) The leakage through and under the dam when up should be less than the least low water discharge of the stream.
7) The foundations should not be liable for injury due to the sudden opening of the dam.
8) When the dam is down, there should be absolutely no obstruction to navigation.
9) The capacity of the weir should be so great that the pass can be raised in a considerable depth of water.
10) It should be possible to pass small freshets, drifts and ice without lowering the entire dam (Bond 1908:713).

Navigable Pass

All of the original movable dams on the Ohio River used Chanoine wickets (see Figure 1-18) for the navigable pass. Francis H. Oxx described the reasons for these wickets' use in an article in *Military Engineer*:

> The Chanoine wicket dam has been chosen because on a river having the characteristics of the Ohio, it is desirable to provide slackwater in times of low water, to have the pass available for open-river navigation during high-water periods, and to eliminate obstruction to the river when floods occur (Oxx 1935:51).

The total length of the movable sections of the dam was such that with all the dam down, the velocity over the pass sill would not exceed four miles per hour. The length of the regulating weir was designed to be sufficient to pass, with all gates lowered, the ordinary summer fluctuations of flow without change in upper pool level. The length also had to permit discharging enough water to maintain the lower pool immediately below the dam at a level within six feet of the upper pool. When the width of the natural channel exceeded that needed for the movable portions of the dam, a fixed section was included. Typically of masonry ogee construction with a crest at or slightly

above upper pool level, the fixed section ranged in length between 57 and 890 feet on the Ohio River (Engineer School 1940:316-317).

As J.W. Arras wrote in an article published in the *Proceedings of the Engineers Society of Western Pennsylvania*, engineers modified the Chanoine wicket pass as a result of testing at Davis Island dam:

> Formerly they were constructed of a heavy wooden framework with interior panels of 2 in. planks, while the more recent wickets are built of the same thickness throughout their width, either of three or of four timbers running longitudinally. The prop was originally designed as a round shaft for the upper half of its length, while the lower half was much heavier and flattened vertically, but retaining the thickness of shaft above, resembling in appearance the old style paddle-shaped oar. Just what was the purpose of this peculiar design is not clear, since a uniform distribution of metal, practically in the form of a round shaft recently experimented with, apparently affords a much more rigid and desirable prop in every way. Except to build them materially heavier, and very recently to slightly alter their internal bracing, no changes of consequence have been made in the construction of the horses.
>
> The most valuable improvement is probably that made in the hurter, introduced in several dams, and which has been sufficiently tested to indicate its worth over the old Pasqueau hurter in use at Davis island dam. That hurter was designed to be set on the top of the dam foundation, and provided a very narrow extension for carrying the prop after its return to the main track or runway. Consequently, there was continual trouble in retaining the prop on the hurter, and when off, not only required considerable time for replacing, but almost invariably resulted in more or less injury to the floor of the structure. The new hurter has practically overcome all of these objections. Its downstream half is trough shaped, gradually winding from the fixed step or main prop support to a width of two feet at the lower end. When set, the top edges of its guard walls are in the plane of the dam floor. This renders it almost impossible for the prop to leave the hurter altogether and, in the event of such an occurrence, makes its return much easier (Arras 1908:249-250).

In his article on Ohio River movable dams, Francis H. Oxx described the design of the Chanoine pass (Plate 1-22; Figures 1-22 and 1-23):

> Each wicket in the navigable pass is built of oak timbers and is about 10 inches thick and 3 feet 8 inches wide, with a length dependent on the lift at the dam. Between each two wickets, which are independent of each other in action, there is an open space of 4 inches. This space is closed when necessary by placing a small square timber, called a needle, cornerwise between the wickets. Needles are usually from 4 to 6 inches square in cross section. Running the full length of the pass, at most of the dams, is a 14-inch by 14-inch oak sill, protected by steel plates, which is set on and bolted to the concrete foundation of the dam. The sill acts to brace against and align the butts of the wickets when they are in an upright position....

Plate 1-22. View from abutment showing Chanoine pass wickets, Dam #41. February 1938. From the files of the Louisville District, U.S. Army Corps of Engineers.

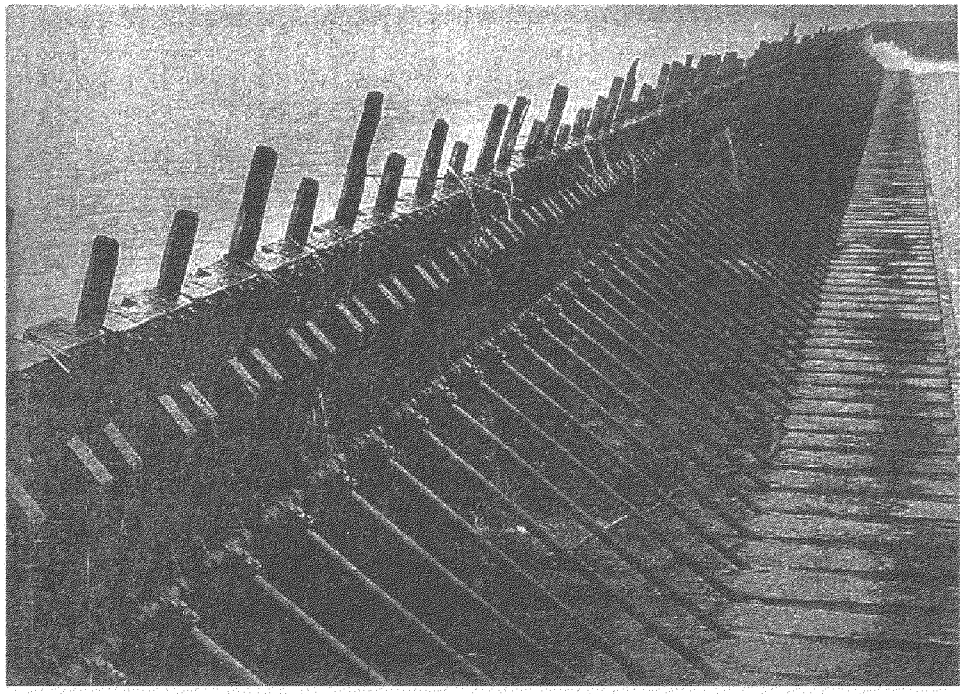

Plate 1-23. Locks and Dam No. 41. Maneuverboat lowering Chanoine pass wickets. January 30, 1940 (U.S. Engineer Office, Louisville District 1940). From Still Photographs Branch, National Archives.

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Figure 1-22. Typical section. Chanoine wicket. From files of Louisville District, U.S. Army Corps of Engineers.

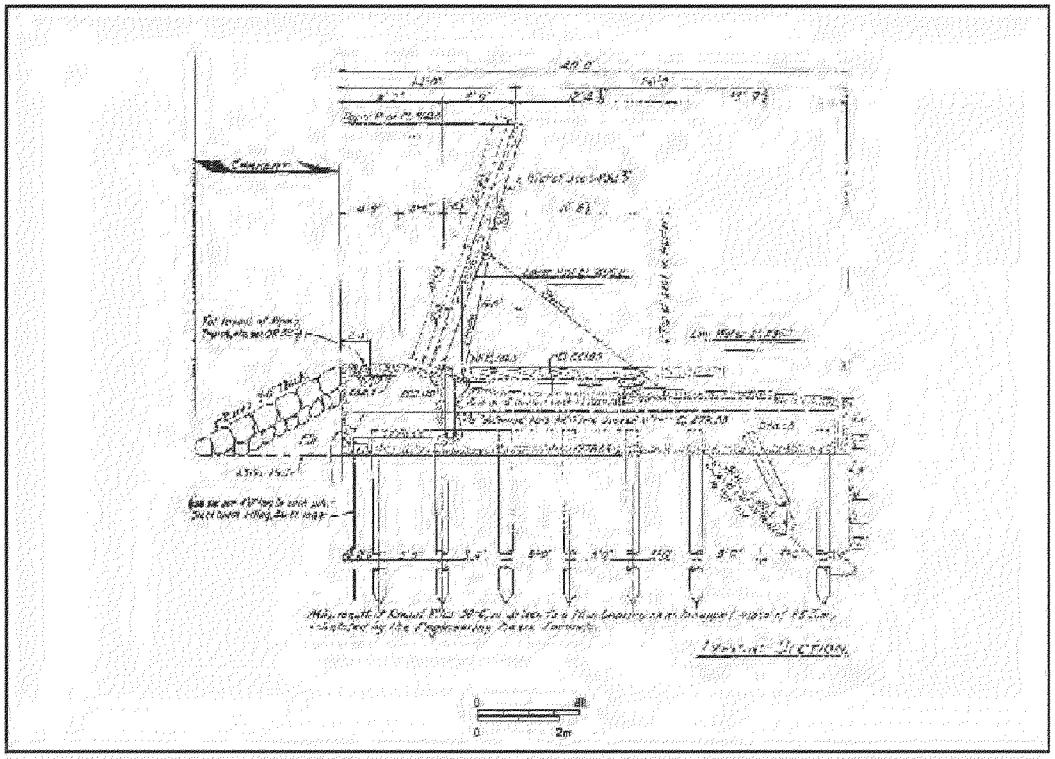

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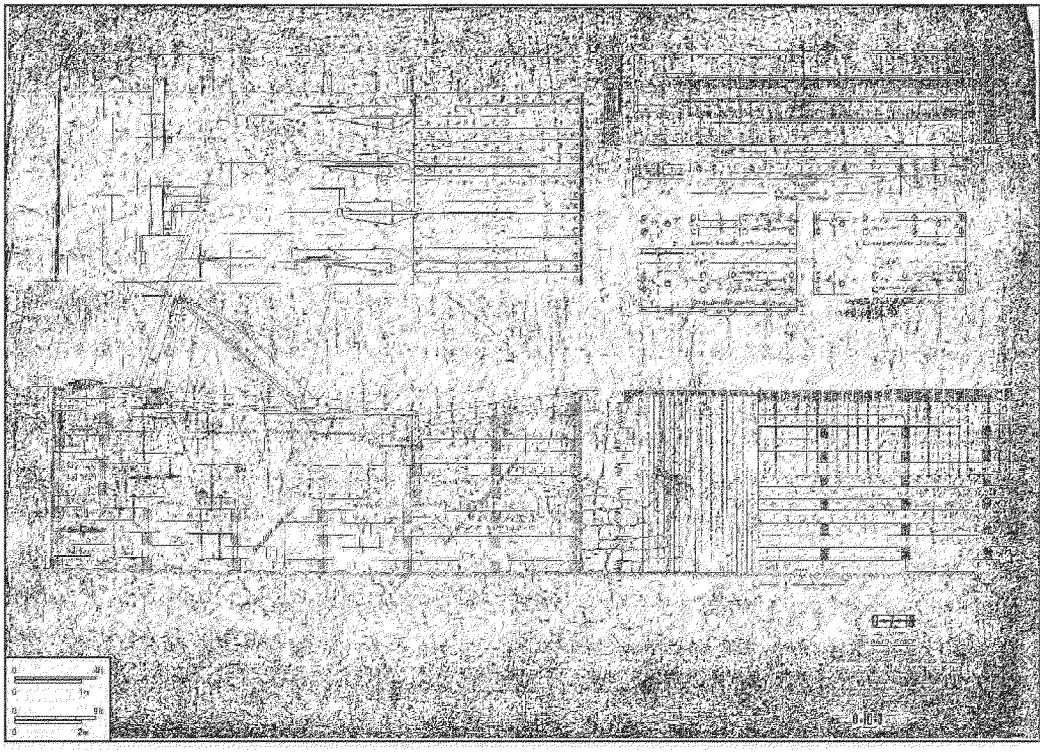
Figure 1-23. Ohio River Dam No. 2. Plan and elevation of Chanoine dam for navigable pass (Pittsburgh District n.d.). From Cartographic Branch, National Archives.



> The wicket itself is...a heavy timber shutter pivoted to a link-like steel frame called a horse, which, in turn, is pivoted to the foundation and which restrains the wicket from lateral displacement. The horse is attached to the wicket below its transverse axial line by means of a suitable horizontal shaft and the necessary bearing, or wicket, boxes. The other end of the horse is connected to the concrete base just downstream from the sill, through a second horizontal shaft and the horse boxes. Attached to the upper shaft of the horse and free to rotate on it is a long heavy forging called a prop about 5 inches in diameter and may be of any length between about 14 and about 18 feet, depending upon the height of the wicket it supports. Its lower end rides in grooves in a cast iron hurter which is imbedded in the foundation....The hurter has two grooves, one to guide the lower end of the prop when it is moved forward and another to guide it when it is moved backward. The first of these grooves contains a shoulder against which the prop rests when the wicket is in an upright position (Oxx 1935:52).

The wickets were raised and lowered by personnel aboard a maneuver boat (Plate 1-23). These boats, which measured about 60 by 22 by four feet, were equipped with fenders for holding the boat off the wickets. Close to the forward end of the boat two spuds were installed, each of which was long enough so that it would bear against a wicket below the hinged point of the wicket when the boat lies along the upstream face of the dam. The spuds were designed to prevent the wickets from tipping over.

Each maneuver boat was provided with a stern capstan engine, a three-drum hoisting engine, an electric light plant, and a compressor. Sibert described the process of raising and lowering the wickets:

> The wickets are raised by a wire line leading from the hoisting engine around a sheave held at the end of a structural-steel beam, which projects from the bow of the boat. The wire line is fastened to an iron hook at the end of a long pole, which is used to guide the hook until it engages in the handle of the wicket. After the prop is seated in the hurter, the wicket is assisted in seating itself against the sill by pike poles in the hands of the dam-tenders. In lowering the wickets, the upper ends are pulled slightly up stream, until the prop unseats itself, when the wicket is allowed to fall upon the foundation behind the sill (Sibert 1908:1209-1210).

A good crew could raise the navigable pass section of the dam in about three and one-half hours (Johnson 1975:230).

As originally planned, the lift of the Ohio River dams would not exceed eight feet, which required the use of wickets about 16 ft. long. Later, 18-ft. wickets were used, and one of the last dams to be constructed with wickets had 20-ft. wickets with a lift of 12 ft. (Kutz 1930:433).

In addition to the navigable pass wickets, each of the movable dams included one or more regulating weirs. Thirty-four of the dams had Chanoine weirs similar to the dams in the passes except for higher sills and shorter wickets. Thirteen of the dams were equipped with Bebout weirs, and one, with a weir of the Boulé type. In addition to the wicket weirs, all dams except two contained at least one beartrap for the rapid lowering of the pool in the event of a quick but

temporary rise and for the passage of floating ice and drift (Oxx 1935:51-52).[2]

The function of the beartraps and other weirs was to regulate the pool levels within certain limits without having to resort to lowering of the wickets in the navigable pass. Beartrap weirs were structures of iron, steel and wood in the form of two leaves, hinged at their outer ends. The lower leaf of the bear trap is a hollow structure like a pontoon, into which air can be forced to increase its buoyancy by displacing the water. By the effect of this buoyancy and the pressure due to hydraulic head caused by raising the wickets in the navigable pass, the lower leaf rises into position, carrying on its upper surface one edge of the upper leaf. When the beartrap is up, it forms an A-like structure supposed to bear some resemblance to the deadfall used in trapping bears. Beartraps were usually two in number and were operated independently of each other (Anonymous 1923:51).

In Dams No. 13, 21, 22, 23, 24, 25, 27, 30, 39, 43, 45, and 48, a portion of each dam was furnished with an automatic wicket. This wicket was designed by Guy B. Bebout, assistant engineer in the Army Corps of Engineers Wheeling District, and bore his name. It was used as a substitute for a Chanoine wicket or weir, or in the case of Dam 21, as a substitute for a bear trap (Anonymous 1923:52).

A-Frame weirs

The A-Frame weir was used only at Dam No. 6 (Figure 1-24). This 120-foot weir was developed by Benjamin Franklin Thomas, a civilian engineer, based on extensive experiments on the Big Sandy River. His design represented an effort to make the trestles of service bridges function as a dam, thereby eliminating the need for wickets. Each metal trestle, instead of supporting a walkway from which Chanoine wickets were raised, took the structural form of the letter "A". The upstream leg of the A was so wide that it touched the next when in raised position, forming a solid surface which could serve as a dam. The installation at Dam No. 6 did not work well, becoming covered with sand and gravel shortly after installation. The A-Frame system was adopted on the Cumberland River and served successfully on that waterway until replaced by modern structures in the 1950s (Johnson 1985:115).

Beartrap weirs

Josiah White of Philadelphia invented the beartrap gate for use on the Lehigh Navigation. The first beartrap was completed in 1819, and a dozen more were installed the following year (WVU n.d.:I:26).

Beartraps were used at Ohio River dams as automatic weirs for the regulation of the pool levels and as a drift pass (Sibert 1908:1206; Figure 1-25). Beartrap weirs were constructed of iron, steel, wood and concrete. Each trap was built in two leaves, hinged at their lower edges. The lower leaf (Plate 1-24) is a hollow member built entirely of steel plates and beams a containing on the under surface a series of compartments averaging three by six feet in size. Compressed air could be pumped into the compartments to force out the water if it was desired to increase the buoyancy of the leaf. The upper leaf was constructed of 8 by 10 inch oak timbers, reinforced with steel beams (Plate 1-25). The lower leaf was equipped at its upstream edge with rollers to
decrease the sliding friction between the leaves. In a raised position, the leaves form an inverted V with the upper leaf resting on the top edge of the lower leaf. The bear traps were generally

[2] The movable dams that lacked beartraps were Dam #21 and Dam #48.

installed in pairs at each dam. The traps were installed between 12 to 14 foot wide and 100 foot long concrete piers. Old bear traps varied in size between 50 and 120 feet, while newer bear traps were 91 feet in length. The maximum clear opening of the newer bear trap was about 15 feet (Kutz 1930:435).

Operation of the beartrap was made possible by apparatus which permitted the hydrostatic pressure on the under surface of the leaves to be changed. To lower the trap, a filling valve was closed and an emptying valve opened, discharging water from beneath the leaves into the lower pool. The leaves fell gradually as the upward water pressure was diminished. When the crest had been lowered, the filling valve was reopened. The operation of raising the trap was the reverse of lowering (Oxx 1935:53-54).

Except for limited trouble caused by sediment deposits under the beartrap leaves and in the filling and emptying culverts, the operation of the modern beartraps proved satisfactory and dependable. Sediment deposits could be minimized by proper arrangement of the culverts and valves to permit flushing of deposits.

The first Ohio River beartraps, installed at Davis Island in 1889 were made of wood and were 52 feet long.[3] In about 1905, the original beartrap was replaced by a new beartrap with leaves heavily bound with steel. William L. Sibert described the next bear traps to be installed on the Ohio, those of Dam No. 6:

> ....two beartraps were installed, each being 120 ft. long. The principal members were steel filled in with wood. The leaves were proportioned on the basis of 100 lifting force to 80 downward. In order to assist the raising of the gates, arrangements were made for increasing the buoyancy by air forced to the under side of the lower leaves. The air was intended to be pocketed between the ribs of the girders. This proved to be of little value, because the air could not be retained where it was needed (Sibert 1908:1206).

During the twentieth century, beartrap technology evolved. Steel was substituted for wood, and the lower leaf was modified in design. In later beartraps, the leaf was built as a flat steel tank which was filled with air to give it buoyancy (Bell 1923:405).

Wicket regulating weirs functioned as supplements to the beartraps. The wicket weir was less suitable for certain purposes because of its slow operation, and more suitable for others because of its greater capacity (Engineer School 1940:29).

[3] The installation of the beartrap weirs at Davis Island followed the 1886 installation of dual, sixty foot wide beartraps on the Kentucky River at Beattyville, Kentucky (see Johnson and Parrish 1999:101).

Plate 1-24. Dam No. 36 Bear Traps. Lower leaf showing hinge. November 1, 1922. From the files of the Louisville District, U.S. Army Corps of Engineers.

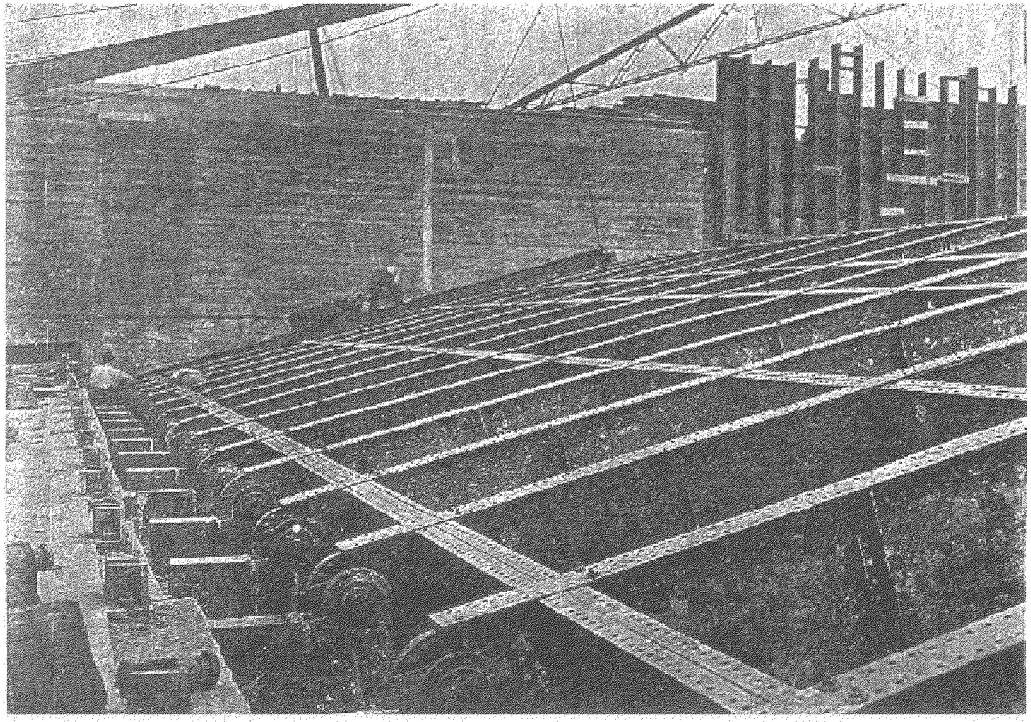


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Plate 1-25. Bear Trap No. 1, Ohio River Dam #47. October 24, 1927. From the files of the Louisville District, U.S. Army Corps of Engineers.

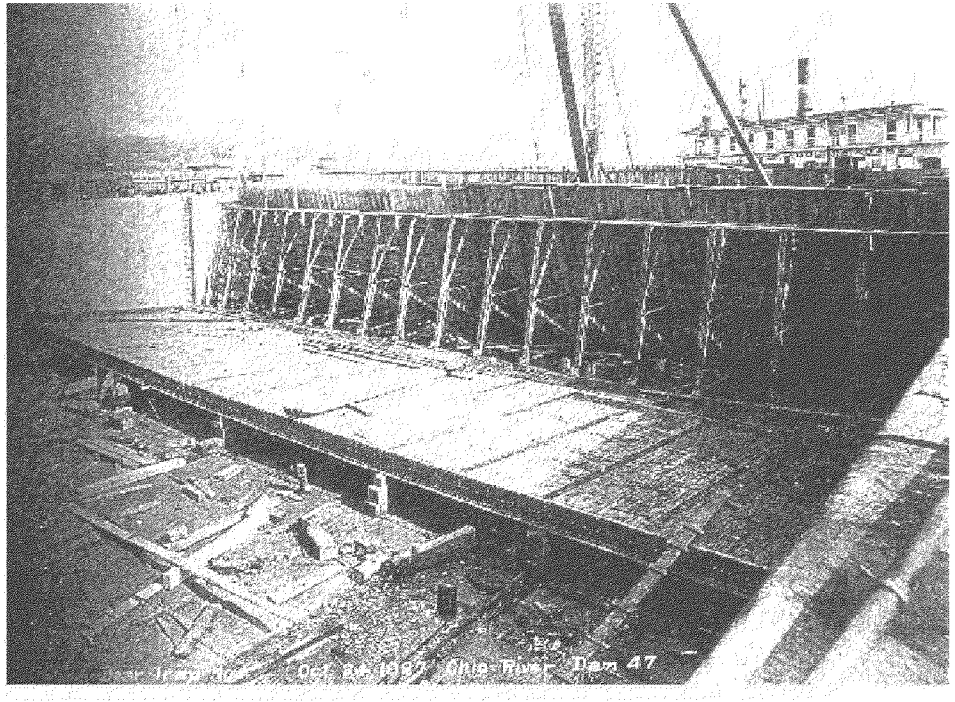


Figure 1-24. Ohio River. Movable Dam No. 6. Details of A-Frame dam and escape bar (Bowman 1899). From Cartographic Branch, National Archives.

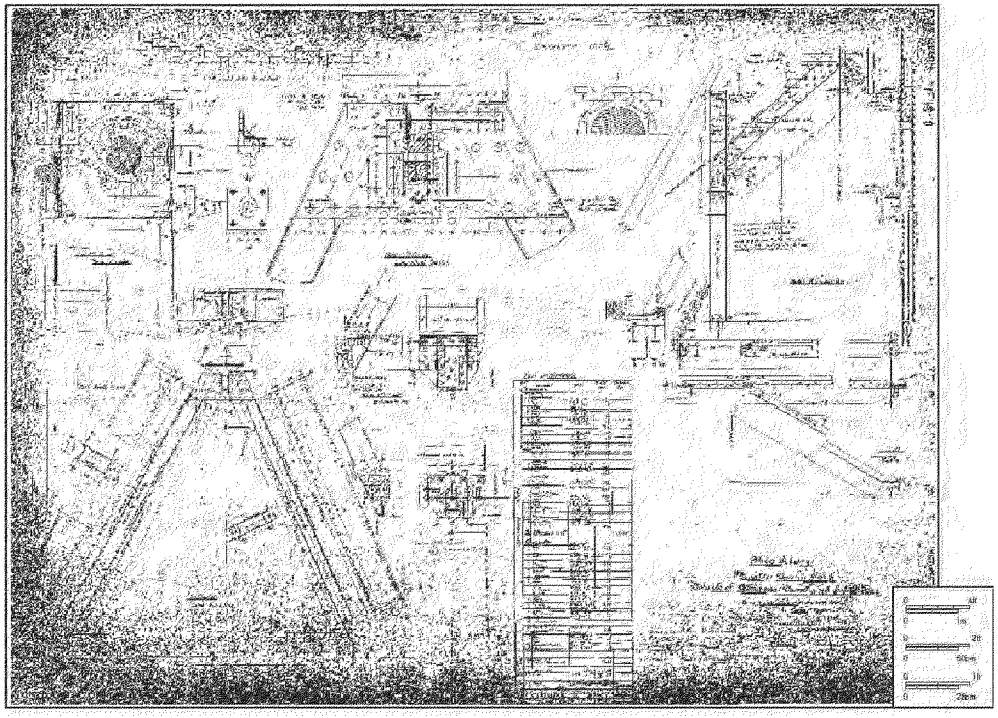
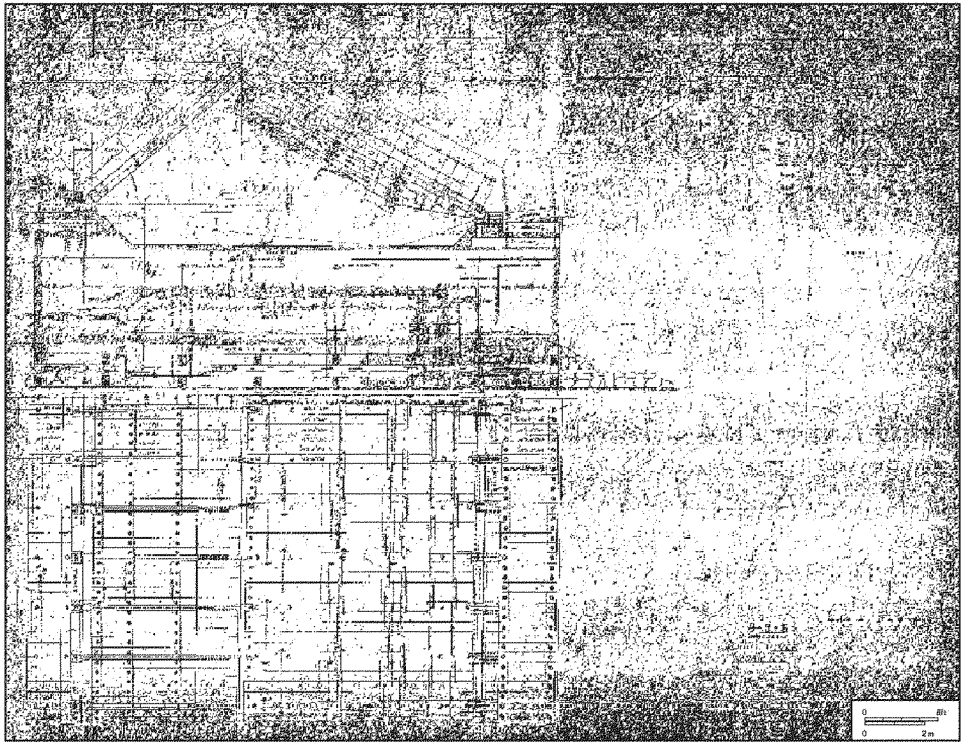


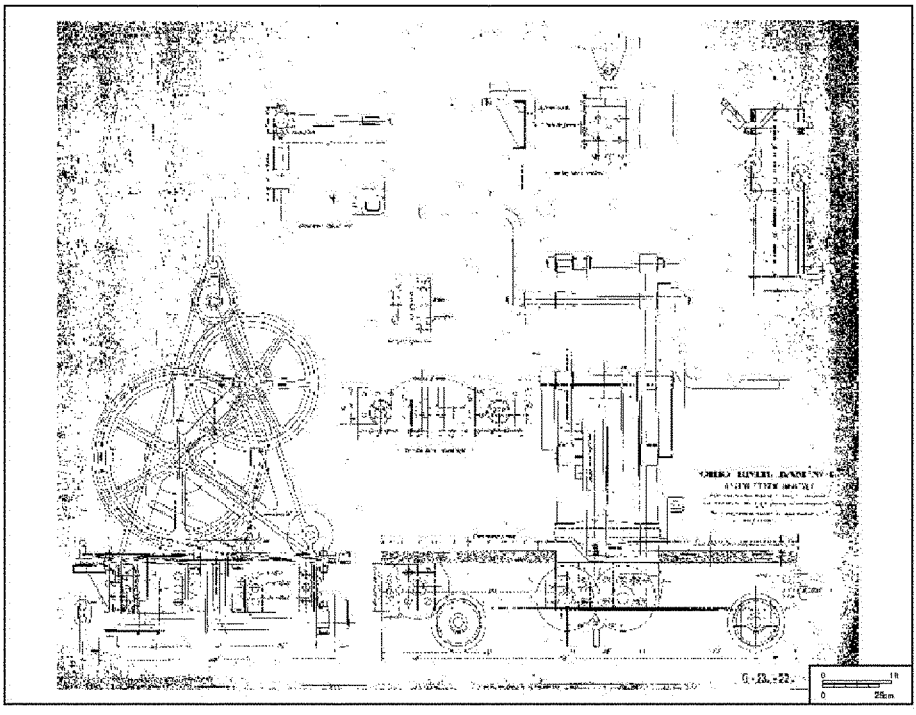
Figure 1-25. Ohio River Dam No. 2. General plan of bear trap dam (U.S. Engineer Office Pittsburgh 1903). From Cartographic Branch, National Archives.



Chanoine weirs

The Chanoine weirs had sills placed somewhat higher than the Chanoine pass to allow easier operation. These weirs were used in conjunction with the beartraps to pass moderate rises exceeding the capacity of the beartraps. The length and number of regulating weirs varied with location (Bond 1908:715).

Figure 1-26. Ohio River Dam No. 4. Winch for operating Chanoine weir (Cutting n.d.). From Cartographic Branch, National Archives.



In the upper river, regulating weirs were small-scale replicas of the Chanoine dam. The earliest Chanoine weirs on the Ohio River were located between the beartraps and the abutments of all upper river dams except No. 6. Rather than being raised by maneuver boats, as were the passes, the wickets were raised by a winch that ran on a structural steel service bridge on the weir foundation (Sibert 1908:1208; Figure 1-26).

Sibert described the operation of these weirs:

> The latest weir service-bridges for these dams have trestles 8 ft. apart, center to center, the trestles being arranged to rotate about their bottom axles, which turn in junction boxes anchored to the foundation....When raised, the trestles are kept

> in place by steel floor-panels, each hinged at one end to the top of a trestle, and held at the other end by pins attached to the adjoining trestle, the pins passing through holes in castings attached to the end of the floor apron. The floors form a track for the winch used to operate the wickets, and serve also as a footbridge for the dam-tenders (Sibert 1908:1209).

The Davis Island Dam was operated using a hand-operated winch, while the winches for Dams 2 and 5 were operated by compressed air (Sibert 1908:1209).

At other dams that used Chanoine wicket weirs, the weirs were equipped with tripping bars. The tripping bar was a flat piece of metal with teeth installed to move along, parallel to the sill, just under the feet of he props. It was operated by machinery located on the abutment or the nearest beartrap pier. The teeth were arranged so as to strike each prop in turn and pull it sideways, disengaging the prop from the hurter shoulder and causing the wicket to fall. The wickets were raised using the same method as the navigable pass wickets (Oxx 1935:54).

Bebout weirs

The wickets used in Bebout weirs were similar to those used in Chanoine dams (Figure 1-27). The major difference was that the supporting frames were constructed to permit the wickets to fall automatically when the rise in the river reached a specified amount. The horse consisted of two arms coupled together in the form of a hinge by a horizontal shaft. The prop was also a trussed structural steel member. The upper ends of the props and upper horse arm were coupled to each other and to the timber wicket by a second horizontal shaft free to rotate in the wicket boxes. The lower horse arm and the lower end of the prop were pivoted to the concrete foundation. As long as the head of water in the upper pool was insufficient to cause the wicket to turn on its bracing shaft, the arms of the horse remain in tension. When the head increased to an extent that the wicket is no longer held against the sill, the tension dropped to zero and the frame collapsed.

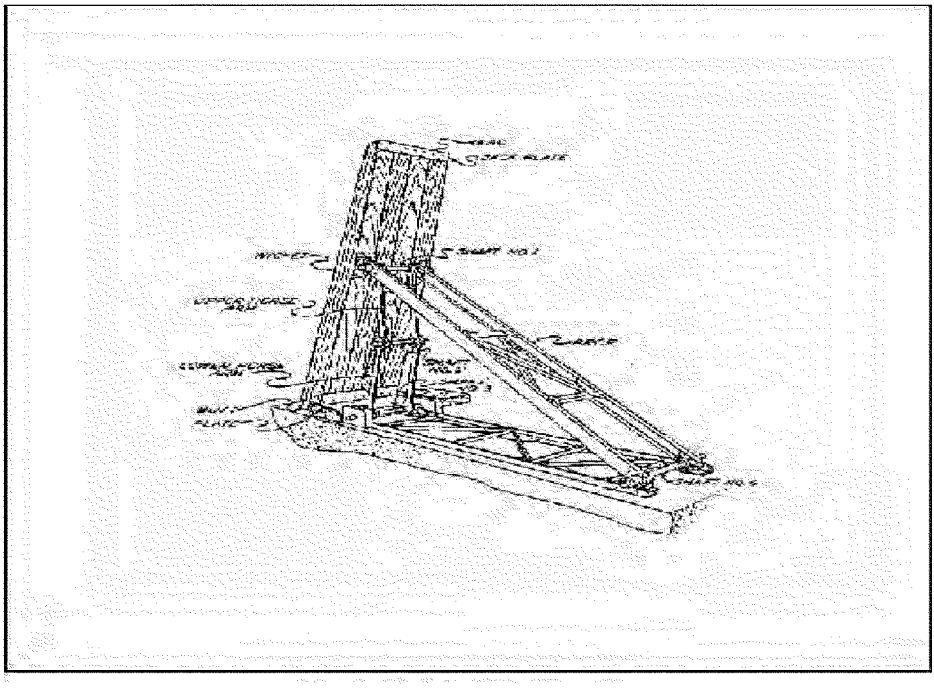
A disadvantage of the automatic tripping feature was that wickets could be tripped by the bow waves or wash of passing vessels, or by direct impact of either vessels or heavy drift (Engineer School 1940:17).

Bebout wickets were raised by the dam-tender working from a maneuver boat. The raising was accomplished by hooking the wicket line to the top of the wicket. If hand lowering of the wickets was necessary, the tops of the wickets were simply pushed downstream with a spar or pike pole (Oxx 1935:54).

A Bebout wicket weir was placed in service at Dam No. 13 in 1915. Cited advantages of this weir included:

1) It can be raised at any open river stage to the top of wickets without any serious loss of time.
2) It can be raised against any difference in pool levels, sufficient power being applied at the chains.
3) It can be lowered under all conditions of river stages and pool levels.
4) When raising the wicket, drift cannot obstruct or become entangled in the parts to such an extent as to prevent raising.
5) A boat, barge, or heavy drift striking the top of the wicket will cause the wicket to collapse without damage to the boat or dam (Black 1929:206).

Figure 1-27. The Bebout Wicket (Oxx 1935).



Boulé dam

At Dam #41, the regulating weir took the form of gate dam of the Boulé type. The sill of this dam sat 10 feet below normal pool level. The supporting members of the dam were steel trestles placed five feet apart at right angles to the crest line and hinged to the foundation (Plate 1-26). The trestles could be lowered behind the sill when not in use (Plate 1-27). The trestles were raised successively with the assistance of the maneuver boat.

The trestles were connected at their tops with chains long enough so that when one trestle was in raised vertical position, the next two or three stood at an angle with the horizontal. The men on the dam, standing on a plank at the foremost vertical trestle, hooked a line from the derrick of the maneuver boat to the first inclined trestle. The trestle was raised by the derrick to the vertical position and was then latched to the previously raised trestle by means of a forged steel frame.

The curtain of the dam was formed by placing a row of steel plates against the upstream side of the trestles. The plates, which were 10 feet high, slid vertically on the upstream faces of the trestles. They were swung into position by the maneuver boat and dropped under their own weight until the lower edges rested on the water sill. Water pressure forced the plates tightly against the trestles, allowing practically no leakage (Oxx 1935:54-55).

Operations of the Movable Dams

To minimize currents in the lock approach and to insure the maintenance of channel depth, the wickets, weirs, and beartraps ordinarily operated in a certain step by step sequence (Engineer School 1940:72).

In the Pittsburgh District, when a rise was imminent, maneuver boats were put under steam. At the beginning of a rise or when only slight regulation was necessary, the needles were removed from the navigable pass. Maneuvering of the pass wickets and operation of the regulating weirs were usually required when there was a depth of from about 9 to about 11 feet of water in the pools (Oxx 1935:58).

When a completely lowered dam was to be raised the other sections were left open and the pass wickets were raised first to minimize the head opposing their operation. Then the weir wickets, with their higher sills, were raised. With the whole wicket length raised, sufficient head was usually available for operation of the beartraps. These were then raised to make the final closure (Engineer School 1940:29).

If the rise continued, the next step was to place one or more of the beartraps in operation. The amount by which the dams were lowered depended upon both the height and rapidity of the rise. If both beartraps were completely down and the rise was continuing, preparations were made to operate the Chanoine dam. Francis Oxx described this procedure:

> In raising the dam, the wickets are first brought up and the valves are set for raising one of the beartraps. As the upper pool is built up the head normally increases sufficiently to cause the beartrap to rise. The needles are installed in the pass and the second beartrap is raised when desired....it is sometimes necessary to needle the dam as soon as the wickets are raised, in order to secure enough head to operate the beartraps (Oxx 1935:55).

When the dam was up, the weir wickets were lowered to assist in passing rises for which the capacity of the beartraps was insufficient but which were not great enough to provide the stages necessary for open navigation (Engineer School 1940:29).

One of the Chanoine wicket dams, that at Dam No. 26, located about 30 miles north of Huntington, West Virginia, failed after completion. The dam, completed in 1911, failed on August 8, 1912. A special board of inquiry appointed by the Chief of Engineers analyzed the reasons for the failure of the dam foundation.

According to eyewitnesses, the failure began when several wickets in the middle portion of the pass fell as the dam was lowered to the foundation. Immediately after the wickets on either side of these began to move downstream. The break gradually extended to the pier dividing the navigable pass from the first beartrap and almost to the lock wall at the other end. One hundred

Plate 1-26. Dam No. 41. Sections 2 and 3 of new Boulé dam. Trestles raised and first row of wickets in place (Office of the Chief of Engineers 1908). From Still Photographs Branch, National Archives.

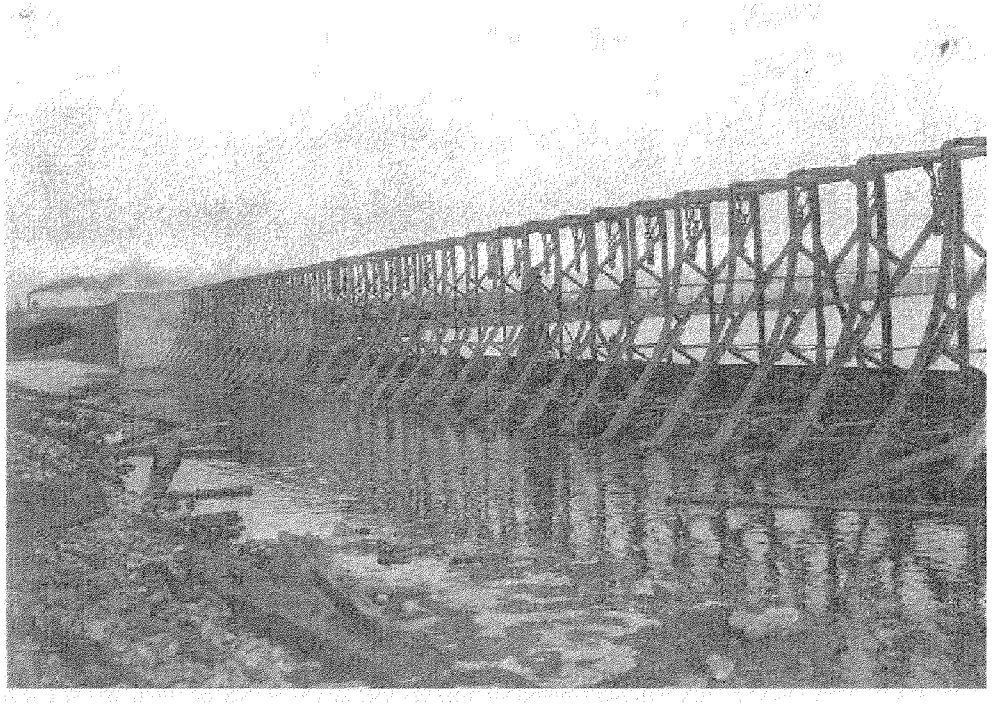


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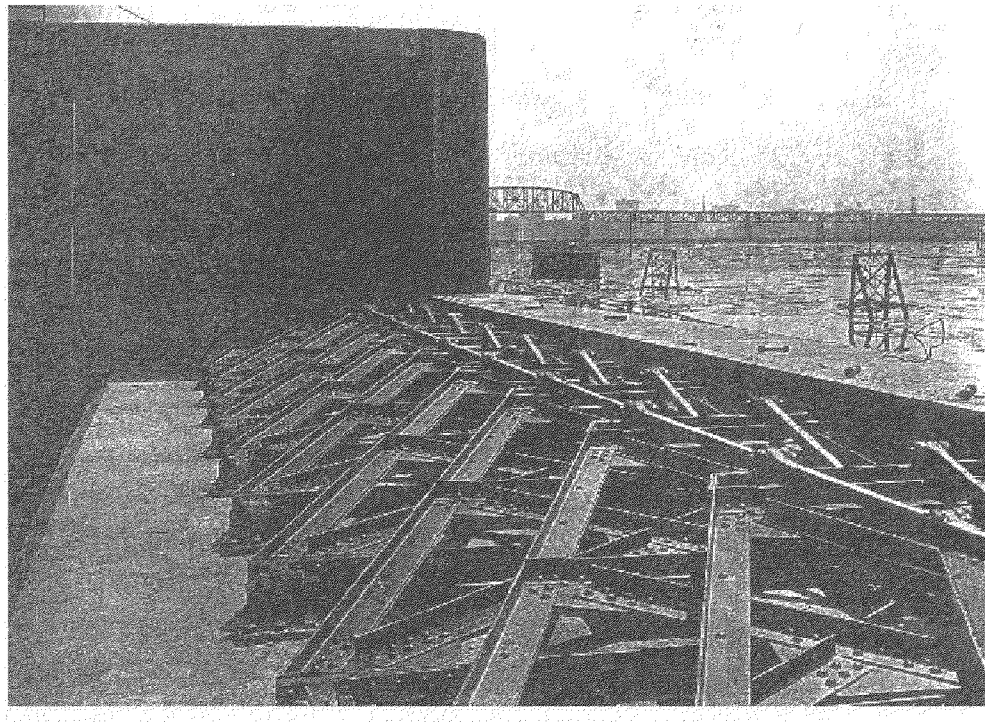
Plate 1-27. Boulé trestles in lowered position, Dam #41. September 14, 1927. From the files of the Louisville District, U.S. Army Corps of Engineers.



and twenty-nine wickets remained standing in their vertical position, while the remaining 21 disappeared beneath the surface of the water. A portion of the foundation moved downstream with the lock end of the portion as a pivot. Total displacement was between three and four feet.

Examination of the foundation revealed that the key near the lock wall had disappeared at some points and had been reduced to a minimal size at other points. The foundation concrete did not abut against the rock immediately above and below the key but was separated from it on each side by an open trench about 1.5 feet wide.

The board members noted that the rock upon which the foundation concrete rested had a very small frictional coefficient and was composed of layers through which water could penetrate and produce an upward pressure on the base of the dam. To prevent a similar accident in the future, the board recommended that a greater thickness be given to the concrete foundation in order to insure sufficient weight to counteract any water pressure under it, that greater care be taken to bond the concrete to the rock by a key having a depth of at least five feet, and, as an additional precaution that the concrete be securely fastened to the rock by anchor rods (Roessler et al. 1915:315-322).

Fixed Dams

During the 1920s, replacement of the original numbered locks and dams on the Ohio began. The first two replacements occurred when Emsworth and Deadman Island complexes, located near Pittsburgh, were built. Emsworth Dam replaced dams 1 and 2, while Deadman Island replaced dams 3 and 4. Both of these replacements were designed as fixed, concrete, gravity section dams.

The Corps selected a fixed concrete dam at Emsworth for several reasons. Major Franklin Bell of the Corps outlined these reasons in an article on the dam:

1) The upper Ohio River from Pittsburgh to the Beaver River has a steep slope. As a consequence, when the dams were down the current was swift and navigation was difficult. Upstream progress for a tow was very slow. Consequently, navigators preferred pool navigation to open channel navigation in this stretch.

2) Due to the steep slope, the back water curve for a low fixed dam for extreme flood height ran only a few miles upstream. The increase of height for any extreme flood at Pittsburgh would be negligible for a fixed dam.

3) The movable dams could not be kept up during high stages of water nor when there was a heavy flow of ice.

4) All the dams then in use on the Monongahela were fixed. None had shown a buildup of silt cited as a detriment of fixed dams (Bell 1923:406).

Protection against failure by sliding was provided by use of a wide base, and by securing adhesion to the foundation by round piles. The piles were also the principal support for the concrete top. Sheet steel piling, driven to rock and with tops embedded in the concrete near the upstream toe of the dam, served as a cutoff wall to prevent water from finding its way under the dam. Bell indicated that the most unusual feature of the Emsworth Dam was the shape of the

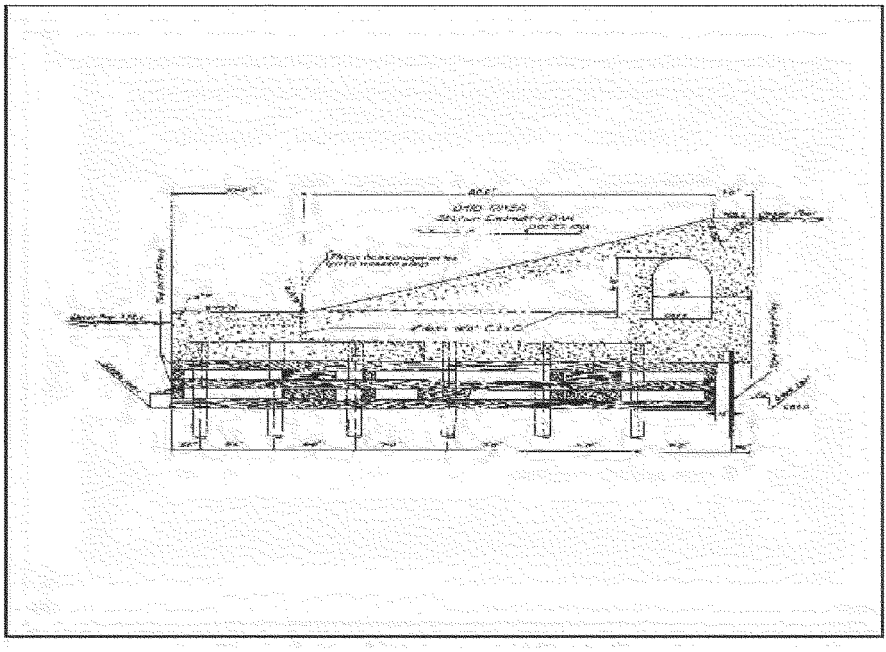
downstream slope and apron, and the absence of riprap, or crib protection, below the dam (Figure 1-28). Bell cited the rationale for the apron design:

> It was expected that at stages when the material below the dam would be eroded by the overflow, the take-off from the apron would be almost horizontal, and that the resulting slope below the dam would be gradual with no deep holes next to the dam. Soundings at various time, below the back channel section of the dam…indicate that the effect has been produced (Bell 1923:406-407).

In his article on construction of Deadman Island Lock and Dam, Hugh J. Casey of the Corps of Engineers cited the reasons why a fixed dam design was chosen for Deadman Island:

In the upper reaches of the Ohio River, the old movable type of dam has proved less desirable than the fixed type. The steep slope of the stream, the rapid fluctuations of stage, the dangers of running ice, and the shorter periods in which open river navigation conditions obtain, all tend to make the operation and maintenance of movable dams difficult. The advantages of open river navigation are at a minimum and the disadvantages inherent in the movable type of dam are always present. The fixed type of dam, in providing a fixed pool, at decreased cost with greater ease of operation and maintenance, will supersede movable Dams Number 3 and 4 (Casey 1929:444).

Figure 1-28. Section of Emsworth Dam, Ohio River (Bell 1923).



Beginning in the 1930s, Corps engineers designed high-lift dams for the Ohio River. These dams permitted regulation of pool height. They did not contain navigable passes, and thus, all traffic had to pass through the lock. The first of these new dams were of two types. Montgomery, completed in 1936, uses vertical lift dam gates. Gallipolis, completed in 1937, uses roller gates. Subsequent dams constructed on the Ohio River employ either vertical lift or tainter gates. One bay of the back channel dam at Emsworth uses a Sidney gate, a hybrid of the vertical lift and tainter gate.

Ohio River dam design criteria for gated dams provided for clearing maximum river stages with the gates in the fully raised position to avoid the hazard of trapping debris and large floating objects. The criterion chosen specified at least five feet of clearance between the maximum flood stage of record and the bottom of the gates in the fully raised position. Since the range of stage was so great, as much as 80 feet between extreme low and high water near Cincinnati, the piers needed to be quite high (Bruce et al. 1957:1239-7).

Vertical lift gates

A vertical lift gate is, in principal, the basic form of the ordinary Stoney gate. Its distinguishing features as installed on canalization dams being its large size and the type of rollers used. Vertical lift gates are generally framed with trusses or built up girders which support the watertight skin plate or sheathing. The water loads are transmitted to steel girders set in recesses at the pier faces. The rectangular section lifts vertically between guides recessed in the piers. The hoisting machinery is placed atop the piers. The actual contact at points of horizontal support is made through fixed rollers. Sliding side seals are made of wood, metal or rubber strips and bottom seals are made of similar materials (Engineer School 1940:44).

The first vertical lift gates were installed at the replacement dam at Emsworth (Plate 28; Figure 29) and Montgomery on the Ohio River; at Bonneville Dam on the Columbia, at Dam No. 17 on the Warrior River; and at Savannah Bluff (Engineer School 1940:45). The **eight** vertical lift gates of the Emsworth main channel dam and the five vertical lift gates on the back channel dam are described in the first periodic maintenance report for the complex:

> Each gate weighs approximately 128 tons, is 102 feet long center-to-center of tracks, 12 feet 10 inches deep and 11 feet wide, and has an effective damming surface of 100 feet by 12 feet. In cross-section it is approximately rectangular consisting of two longitudinal trusses, each composed of 12 panels, 8.5 feet long, reinforced by vertical and lateral braces. Each gate has a 3/8-inch watertight skin plate on the upstream face and a wrought iron apron on the top.... Each gate can be raised to a point where the bottom is 39.4 feet above the sill level, or 5.6 feet above the highest recorded flood at Emsworth, and lowered to a point where its top is 3 feet below normal pool level. In the latter position, 3 feet of water is allowed to run over it to maintain the pool elevation (USACE-Pittsburgh 1971:6).

Plate 1-28. Emsworth Dam. Main channel. Downstream face of dam looking toward right bank (Pittsburgh Office, U.S. Army Corps of Engineers 1948).

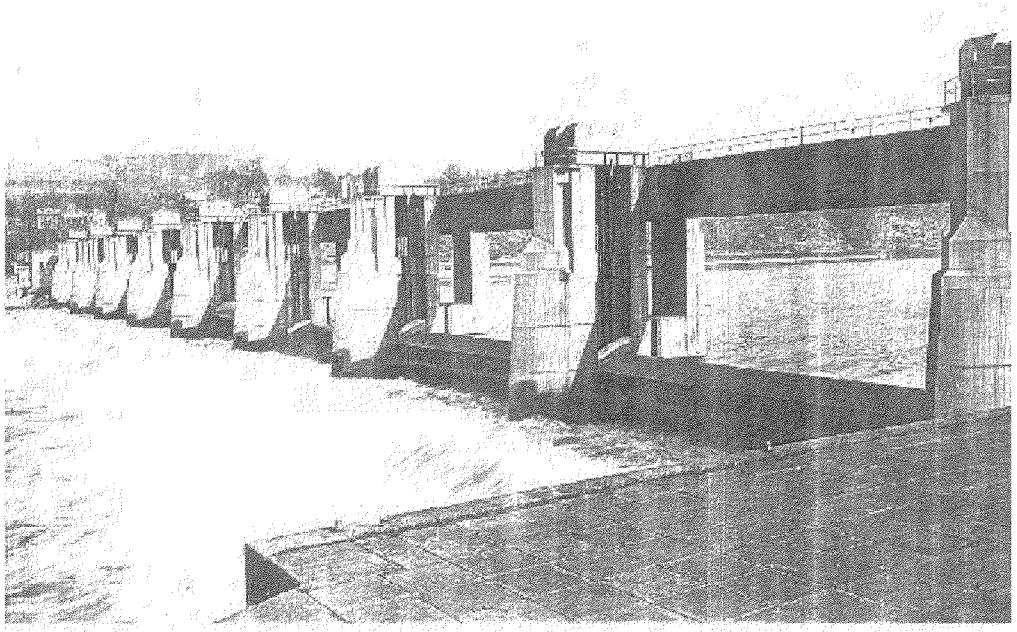
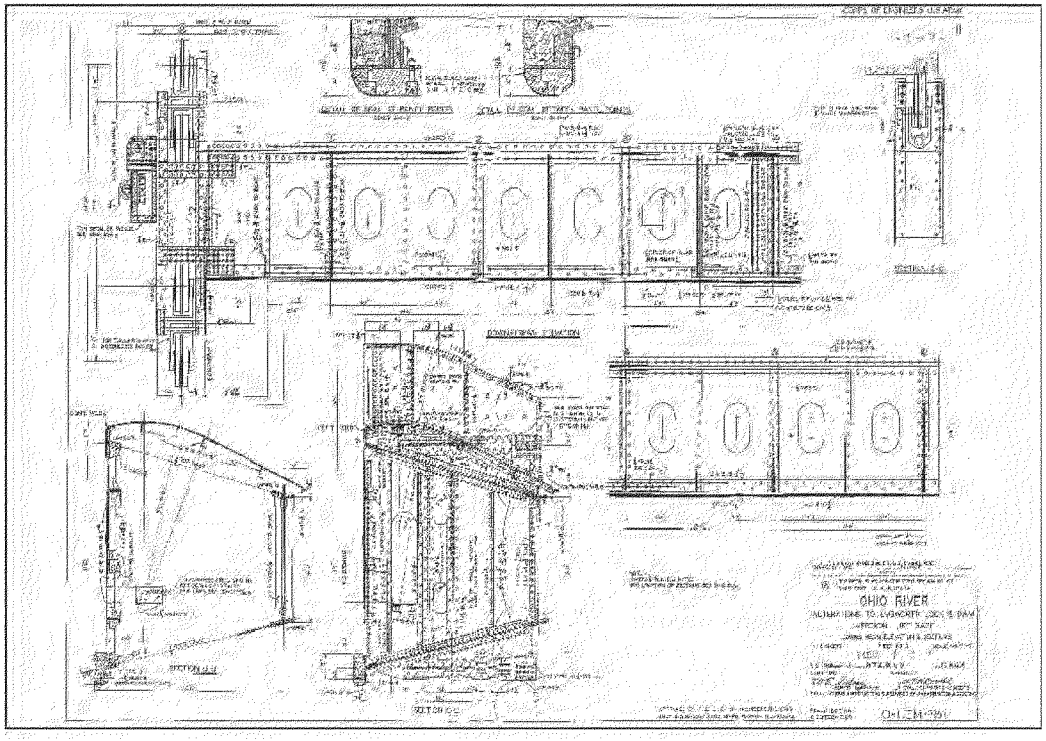


Figure 1-29. Alterations to Emsworth Lock and Dam. Vertical lift gate. Downstream elevation & section (U.S. Engineer Office Pittsburgh 1936). (From USACE-Pittsburgh 1971).



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The Montgomery gate is constructed with three chords but operates as a vertical lift gate (Bruce 1957:1239-7). The design of this gate is described in the first periodic inspection report for the complex:

> The dam has been equipped with 10-100 foot direct lift type gates. The gates are of riveted steel truss type construction. Bottom and side seals are made up from timbers. A device is provided for dogging the gates in the fully raised position. Two hoisting machines are provided for each gate. The hoist mechanism includes shafting, gate guide wheels, lift chains and sprockets external spur gearing, inclosed worm gearing, and two motors for each hoist coupled together with a brake on the end of the shaft of the forward motor (USACE-Pittsburgh 1972b:7).

Montgomery gates are unique in that they are tapered on their ends; the concrete pier's sealing surface is also tapered.

Roller gates

The roller gate was invented by Dr. Max Karstanjen of Mainz, Germany, the director of the bridge department of the Maschinenfabrik Augsburg-Nurnberg (MAN), Germany. The first roller gate dam was built in 1902 on a branch of the river Main near Schweinfurt, Germany. The installation consisted of a single roller about 13 feet in diameter with a width of opening of 59 feet. The roller was raised and lowered by rolling it up and down masonry inclines by means of wire ropes. The gate was hand operated by two winches and required 12 men to operate (Dravo 1947:34).

The dam crest height is adjusted by raising the large steel tube or roller off the dam crest. Professor K.E. Hilgard introduced the roller dam to the United States by discussing it in a paper at the 1904 International Engineering Conference in St. Louis. By the end of 1913, two power dams and two irrigation dams using roller gates were either completed or under construction in Washington, Idaho, and Colorado. The first completed project, the Washington Water Power Company's Long Lake Dam, used three roller gates for spillway crest control (O'Brien et al. 1992:68). By 1928, 250 roller gates dams had been constructed including 24 in the United States (Kemp 2000:106).

The first roller gate dam designed by the U.S. Army Corps of Engineers was Mississippi River Dam No. 15 at Rock Island, Illinois completed in March 1934 (O'Brien et al. 1992:67). Following the completion of this dam, additional roller dams were completed at London, Winfield and Marmet on the Kanawha River. On the Kanawha River, Corps engineers specified that one of the dam gates be fully submergible. Later Mississippi River installations, at dams 4, 3, and 9, 11, 15, and 18 also used submergible roller gates (O'Brien et al. 1992:71-72).

The earlier roller gates consisted of a plain cylinder, the cylinder resting directly upon the crest of the sill when in a closed position. Later gates were developed with aprons or shields projecting downward and upward from the cylinder, thus reducing the diameter of the cylinder for a given height of gate (McAlpine 1934:420). In his article on roller gates, W.H. McAlpine described the construction of these later gates:

> The shell plating of the drum is kept in a cylindrical shape by internal bracing consisting of structural steel cross frames and longitudinal channels. The shell plating varies in thickness along its length according to the strength required. The

> apron is a segment of a cylinder and is made uniform in thickness. It is attached to the upstream side of the drum slightly below its center axis and is held rigidly by struts connected to the drum (McAlpine 1934:421).

Gates were hoisted by means of a multiple side bar chain at one end of the drum. A typical chain was made of special high-strength steel with a minimum working strength of 85,000 pounds per square inch. It was wound part way around the drum and unwound as the roller rose. Power to raise the gate was provided by a large, electrically driven hoisting engine (McAlpine 1934:421).

By the time that the roller gate dam was completed at Gallipolis, more than 160 roller gate dams had been completed in Europe. As of 1939, there were 146 roller gate dams installed in the United States including 22 locations on the Upper Mississippi Navigation (Kemp 2000:115).

Engineers for the Corps believed that roller gates were superior to vertical lift or tainter gates because of the inherent stiffness of the roller tube. This allowed openings of much greater length than previous movable dams. The roller gate also had the advantage of low maintenance and trouble-free operation (WVU n.d.:II:25-26). A 1913 *Engineering Record* article compared gate types:

> The alternative for rollers are Tainter or sliding gates. It is difficult to say exactly where the economic limit lies for the Tainter type, but it may be said with certainty that gates 30 ft. wide and 12 ft. deep are not far from the economic limit. For sliding gates of the Stoney type, those used in the Panama spillways, which are 46 ft. wide and 19 ft. high, are about as large as gates of that type can be built with economy. Furthermore, the Stoney gates, on account of their submerged rollers, with their bushed journals and roller guides, offer too many chances for trouble (as cited in Kemp 2000:109).

In the subsequent construction of the Mississippi River 9-foot channel, it was discovered that roller gates had to be raised above the level to maintain the minimum pool elevation behind the dam in order to pass ice flows. With the gates wide open, the pool was lowered and the great volume of water passed tended to erode the toe of the dam. To pass ice and drift on the Kanawha River, flaps were installed on one roller at each of the Kanawha River projects. Early design studies for the Kanawha River considered the use of submergible roller gates. This technology was rejected in favor of the installation of flaps (McCoy 2000).

Dravo engineers described the operation of the roller gate:

> The standard roller gate consists of a cylindrical steel shell heavily reinforced with internal bracing and having an apron attached to the bottom of the cylinder to give increased damming height.
>
> Flexible steel diaphragms extending out from the upstream side of the cylinder and the apron at each end of the gate are held against the faces of the pier by the water pressure and make water-tight seals at these points. The main body of the gate with its attached apron rests directly on the sill of the opening. The apron and the end seal diaphragm are faced with timber seals.
>
> Recesses are provided in the piers at each end of the gate with the gate ends extending into these recesses. Each end of the gate is provided with a circular

> combined track and rim gear which run on and mesh with a similar track and rack section which is anchored to the concrete on the downstream side of the recess. For the raising and lowering of the gate a hoisting unit is provided at one end only of the gate structure with a lifting chain attached to a fixed point near the upper part of the cylinder and carried completely around the cylinder and thence up to and over the sprocket of the hoisting unit.
>
> The hoisting unit, located on top of a pier, consists of a series of reduction gears, and is motor driven. By rotation of the chain sprocket the chain is pulled up causing a rotation of the gate body upward along an inclined track. The speed of movement on various installations is usually from 6" to 9" vertical lift per minute (Dravo 1947:34-35).

When the gate is in the saddle or zero position, the apron or the main cylinder rests against the sill, the line of contact sealed by a rubber strip. At this position the gate crest is at pool level, and there is no flow either over or under it. When the gate is partially raised, water flows under the gate, between it and the sill. When raised clear of the water, free flow between the piers is permitted (Engineer School 1940:32).

At the time of their installation, the Gallipolis roller gates were the largest roller gates in the world (Dravo 1947:43; Figure 1-30). Each gate measures 29.5 feet in diameter and 120.5 feet in length (Kemp 1991:1). The machinery for raising and lowering the gates is located at the top of the piers in a concrete housing. The gates are operated on a sloping rack and move by an electrically powered gear train which drives a huge sprocket chain connected to the roller gates. Access to the housing is by means of a steel walkway that takes the form of a structural steel Pratt truss (Kemp 1991:2).

Tainter gates

The basic design for what became the tainter gate was developed by American inventors as early as the 1820s and refined throughout the nineteenth century. Thomas Parker, a Wisconsin lumberman, developed the modern tainter gate in about 1880 for use in the lumber industry. He designed the gate to control water levels in mill reservoirs. Not only did the gates control these levels but also passed ice and other debris when necessary. He sold the rights to his invention to Jeremiah Burnham Tainter who patented the gate system in 1886. The Corps of Engineers purchased the rights to use the tainter gate patent. In 1889, Major William Marshall became the first Corps officer to use tainter gates, developing a manual-operated version of them for use on a movable dam across the Rock River in Illinois. Tainter gates were installed in the 1890s on the Fox River in Wisconsin and the Illinois and Mississippi Canal (WVU n.d.:II:9; Johnson 1985:135; O'Brien et al. 1992:79).

In their earliest form, tainter gates were restricted to openings of only 35 feet or less. The first use of tainter gates for the entirety of gate bays on an American river occurred in 1938-1939 when they were installed at Dam 24 on the Mississippi River (WVU n.d.:II:9-10). At this

Figure 1-30. Gallipolis Locks and Dam. Dam. Roller gates general arrangement (U.S. Engineer Office, Huntington 1938). (From USACE-Huntington 1970).

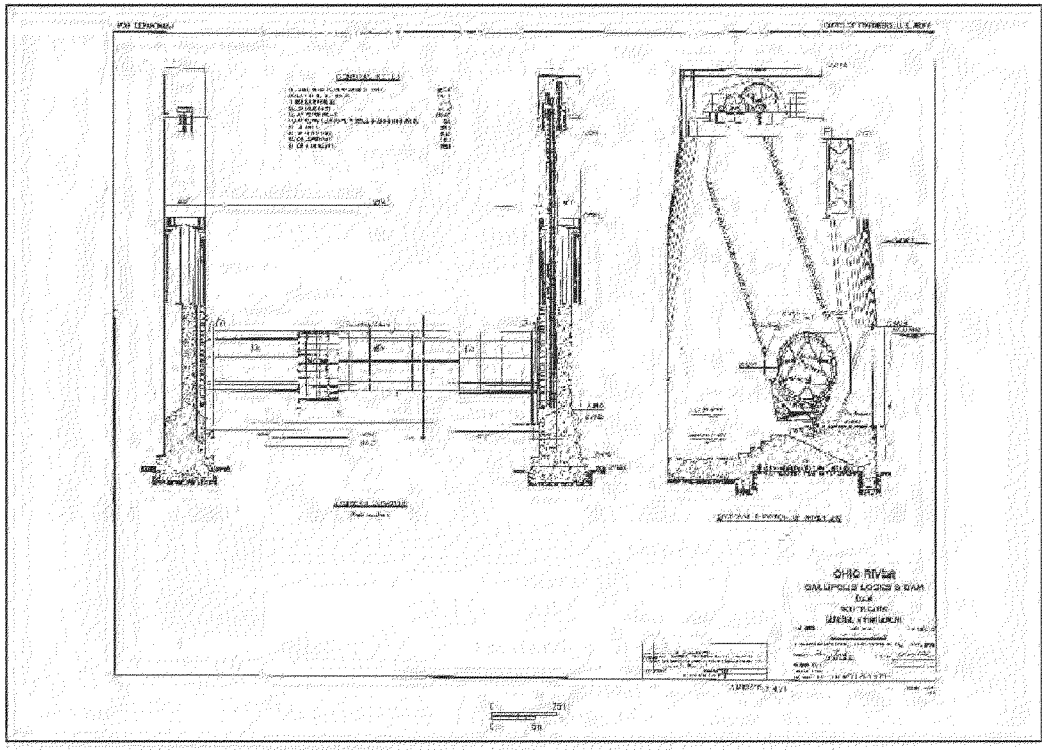

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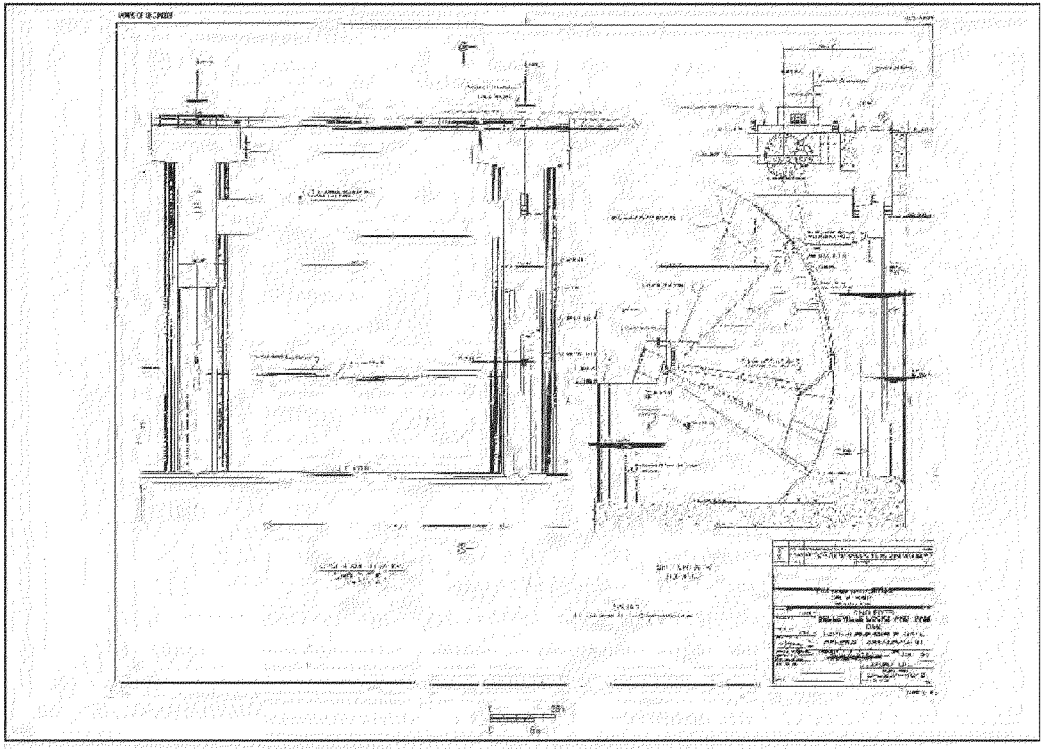
Figure 1-31. Belleville Locks and Dam. Dam. Non-submergible Tainter gate (U.S. Army Engineer District, Huntington 1964). (From USACE-Huntington).



installation, fifteen 80-foot long gates were used and were believed to be the largest Tainter gates constructed to that time (O'Brien et al. 1992:79).

Tainter gates may be divided into two types: non-submergible and submergible. The most common form of tainter gate is the non-submergible (Figure 1-31). A tainter gate is an internally framed sector of a cylinder with a system of radical bracing and a trunnion arm at each end which carries the gate load to a trunnion pin.

The trunnion pin is anchored to the pier, and the arm and gate rotate about the pin. The gates are mounted upstream from the trunnion pins, and the gate skin plate is convex upstream. When the gate is closed, the lower edge of its cylindrical surface is in contact with the sill, making a tight joint. Rubber seals along the end of the gate rest and slide against plates set in the sides of the piers. When the gate is closed against the sill, water stands against the upstream surface of the gate but does not normally overflow. When the gate is partially raised water flows through between the lower edge and the sill (Engineer School 1940:35). The tainter gates on the Ohio River are raised and lowered by wire rope and hoists with spiral drums.

The tainter gates at Racine Dam are typical in design:

> Rubber "J" seals of standard manufacture are used for side seals and bear against seal plates of corrosion-resisting steel. The gates are of welded construction with the skin plates, web plates, diaphragms, tee sections and side frames of structural steel. The hoist cable bearing surface of the side frames and side arms are of low alloy steel. The bottom horizontal lip on the bottom of the gates is of extra high strength steel. The gate body is composed of two longitudinal cells with a stiffened cantilever portion of the upstream skin plate extended approximately nine feet above the top cell (USACE-Huntington 1971:6).

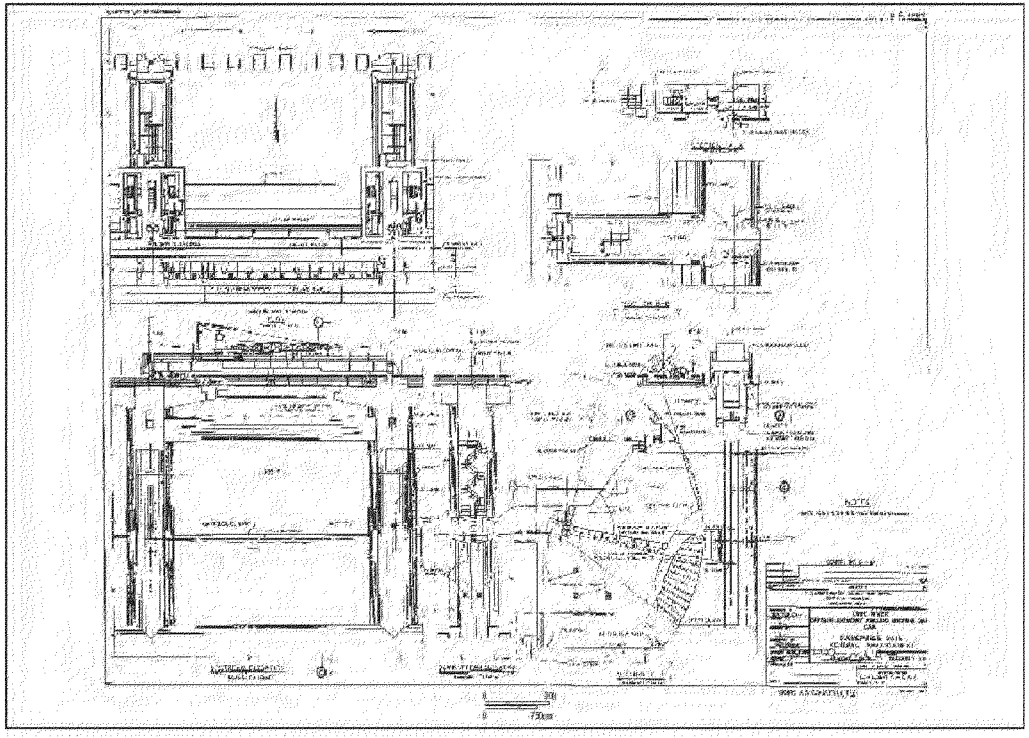
The Tainter gates at Racine dam have tubular cross sections. At Willow Island Dam, the gates have an open framing and sector shape similar to that of the tainter valve (McCoy 2000).

Each of the tainter gates at the Racine Dam is raised and lowered by multiple-cable hoists mounted on the top of the piers at each end of the gate. The two hoists for each gate are synchronized by a torque shaft spanning the gate bay and powered by a single electric motor. A pushbutton control station is mounted at each motor location (USACE-Huntington 1971:7).

The submergible tainter gate (Figure 1-32) was intended to pass large quantities of drift and ice. To do this, the non-submergible gate must be raised until the floating material is drawn into the gate opening. Often the size of the opening necessary to suck the debris from the surface was so great that the amount of pool water lost was substantial. The submergible gate was designed to allow discharge over rather than under it, making it possible to skim off surface debris with a relatively small discharge. The gates were designed so that with the top at pool level, the gate made a tight joint with the sill, and water can pass only by overflow. As the gate was lowered from that position, the bottom seal was usually released, but the principal discharge was by overflow (Engineer School 1940:40).

Typical submergible gates were those installed at Meldahl Dam. The gates are of cellular stressed-skin construction with a radius of 64 feet from the trunnion pin to the upstream face of the skin plate. The gates were designed so that they could be lowered 9 feet from the normal

Figure 1-32. Captain Anthony Meldahl Lock & Dam. Dam. Submergible Tainter gate (U.S. Army Corps of Engineers Huntington 1960). (From USACE-Huntington 1969).



closed position to the fully submerged position in order to pass debris or ice that has accumulated upstream of the gate.

The Meldahl submergible gates suffered from excessive vibration when submerged (USACE-Huntington 1969:9). As a result the gate was modified to eliminate submersion. In 1977, submergible gates at Markland and McAlpine dams were converted to non-submergible. No submergible gates are presently in operation on the Ohio River.

In several instances, the two-part gates were welded together to form a single non-submergible tainter gate. In instances where the original design called for submergible gates, such as at Racine Dam, this type of gate was not included in the final design (USACE-Huntington 1971:6).

The most recently constructed tainter gates are designed as non-submergible. As a result, lighter framing was used. In addition, recent gates, such as those installed at Winfield Dam use hydraulic cylinders as hoists for the tainter gate. These cylinders permitted the reduction in pier height and the setting of upstream bulkheads from floating plant on the downstream side (See Figure 1-21) (McCoy 2000).

Sidney gates

As noted, only one dam on the Ohio River uses a Sidney gate, the back channel dam of Emsworth located between Neville Island and the south bank of the river. The gate closest to Neville Island is a 100 ft. clear span Sidney gate (Engineer School 1940:296; Plate 1-29; Figure 1-33).

The Sidney gate, developed by William E. Sidney, chief mechanical engineer of the Pittsburgh District, Army Corps of Engineers, constitutes a special type of tainter gate equipped with movable or sliding trunnion pins (Plate 1-30). Sidney's invention grew out of experimentation with movable crest gates for dams during the Depression. In preliminary studies for Emsworth, the roller gate and a modified tainter gate were considered in addition to the vertical lift gate. The Sidney gate was a hybrid of the tainter and vertical-lift types (Johnson 1979:247; Bauknight 1937:665).

Sidney developed the gate to overcome the disadvantages of limited maximum clearance of other tainter gate types caused by the fixed trunnion. This disadvantage precluded the use of tainter gates on rivers where stage ranges were great. The pins of the Sidney gate are seated in slots in the pier face which cause the gate to open in the ordinary way, by rotation about the trunnions, until the center of gravity is vertically below the point of lift. From this point the entire gate is lifted to full clearance, the pins rising vertically along the pier tracks. This type of gate was later used at Dam No. 4 and Point Marion Dam on the Monongahela River.

Bauknight described the configuration of the Sidney gate in an article in *Engineering News-Record*:

> It combines certain features of the tainter and the vertical lift types in that it revolves part way and then lifts vertically to the height required to clear the opening. In cross-section, the gate is triangular; the upstream face consists of a girder and the upper and lower legs are trusses with a common downstream chord. The skin plate forms a segment of a circle in cross-section, the center of

Plate 1-29. Emsworth Dam. Back channel. Sidney gate. Gate shown closed. (U.S. Engineer Office, Pittsburgh 1940). From the files of the Pittsburgh District, U.S. Army Corps of Engineers.

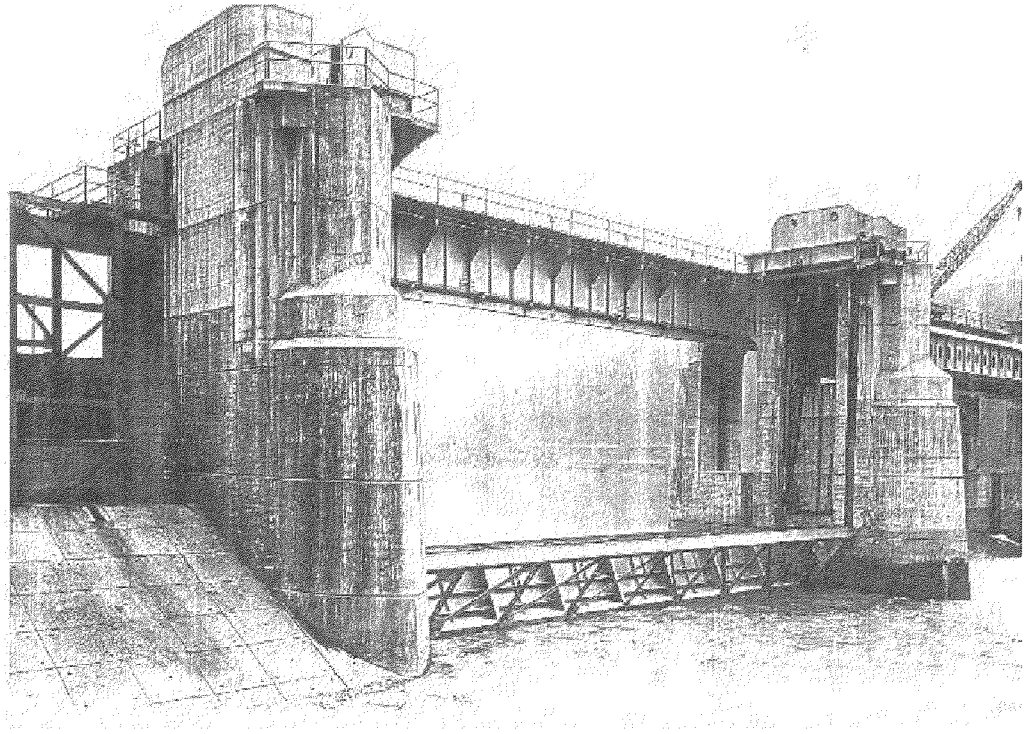


Plate 1-30. Sidney's sectional model. Modified type tainter gate (U.S. Engineer Office, Pittsburgh 1933). From the files of the Pittsburgh District, U.S. Army Corps of Engineers.

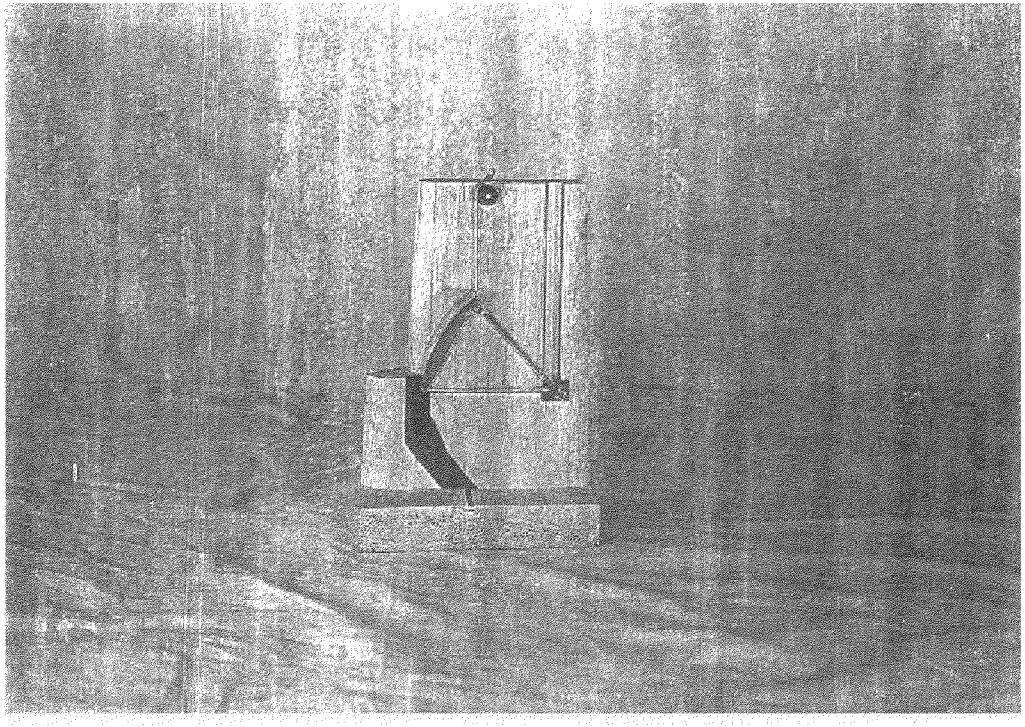
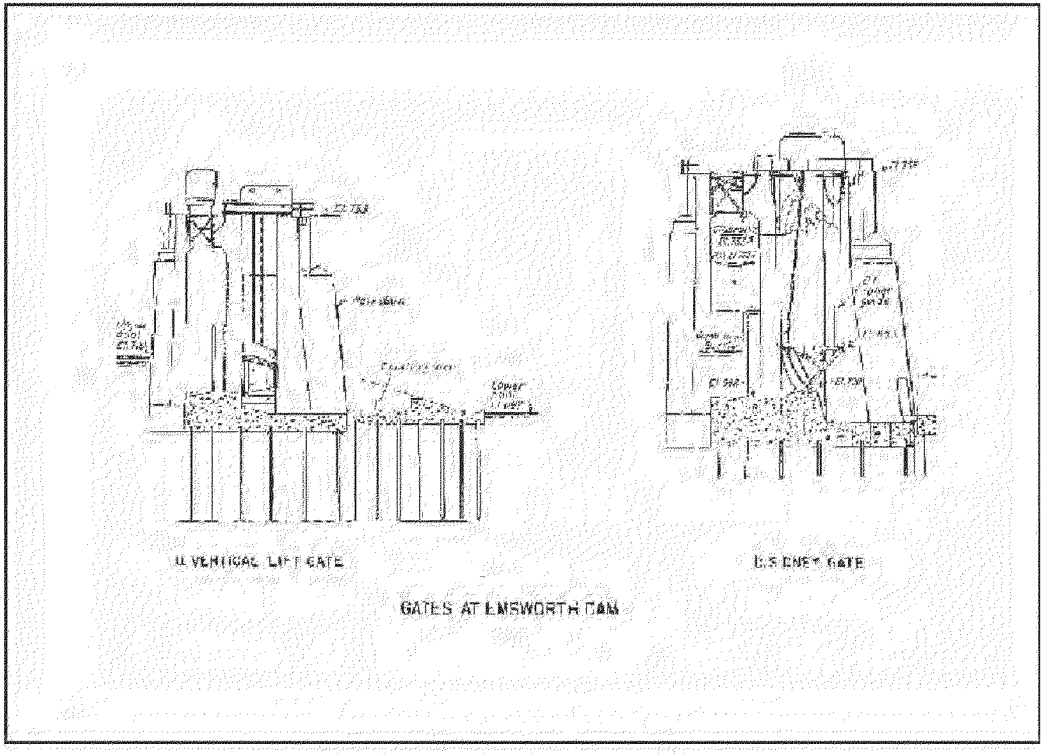


Figure 1-33. Gates at Emsworth Dam (Engineer School 1940).



which is coincident with the neutral axis of the downstream chord (Bauknight 1937:665).

The gate is operated by means of lifting chains and synchronized hoisting units, one at each end of the gate. When it becomes necessary to provide a larger discharge area during flood stages,hoisting is continued after the gate has reached the limits of its rotation, at which point he entire weight of the gate is supported by the chains. The maximum travel limit for the Emsworth installation is 38 feet above the sill (USACE-Pittsburgh 1971:8).

Bauknight cited some of the advantages of the Sidney gate:

- As the entire weight of either the Sidney or lift-type gate must be suspended from the lifting chains, it follows that the lighter the gate the smaller the cost of chains and hoisting machinery [The Sidney gate, as designed, was considerably lighter than the vertical lift gate.]

- The depth and width of the recess in the pier is much less for the Sidney gate than for either the lift or roller gate, and where suitable foundation conditions exist, a smaller pier may be used for the Sidney gate than the other two types (Bauknight 1937:666).

To test the performance of a Sidney gate, a one-fifth scale model of the gate to be erected at Emsworth was erected at Dam No. 3, Allegheny River during the summer of 1935. It performed satisfactorily (Bauknight 1937:666).

Emergency and Maintenance Lock and Dam Closures

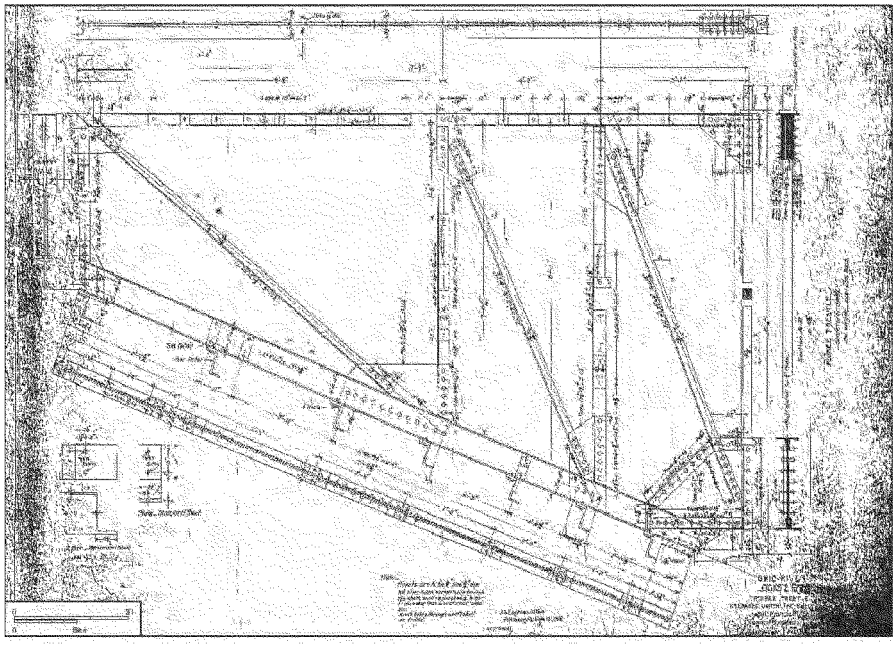
In an article published in the *Transactions* of the American Society of Civil Engineers, C.E. Blee divided supplementary lock closures into three categories:

> 1) Provisions for unwatering the lock and its operating equipment for ordinary routine inspection and maintenance, in which closure can be made under conditions of balanced head;
> 2) Provisions for safeguarding, or preventing damage to, lock operating gates and other equipment; or
> 3) Provisions for making an emergency closure of the lock under an unrestricted flow of water resulting from damage of disastrous proportions to the lock gate (Blee 1951:853).

A fourth category of lock closure, not mentioned by Blee, is to pass ice and drift in the approach to the locks. Lock closures on the Ohio River Navigation System are used for the first, third and last mentioned purposes (McCoy 2000).

The early numbered locks used a Poirée needle dam to close the chamber in case of an accident to the gates. A row of steel bents was place across the chamber, the bents being pivoted at their feet to swing laterally. The bents normally lay in the recess across the concrete floor. To close the opening, the bents were raised by chains and were connected by rigid members at the top. Timber needles were then set in place by hand from a bridge laid upon the bents, the lower end

Figure 1-34. Ohio River Locks 2 to 6. Poirée trestle (Arras 1916). From Cartographic Branch, National Archives.



of each needle rested against a sill and the upper end against the bridge (Anonymous 1909b:236-237; 34).

The Poirée dam was developed by M. Poirée in 1834 for a 72-foot navigable pass in the dam as Basseville, France on the River Yonne. This improvement over earlier pass technology involved a series of iron bars fastened to the top of iron frames to support wooden spars called needles used to close the path. A major feature of his invention was the manner in which the frames were removed when the pass was to be opened. This was accomplished by removing the needles by hand, unhooking the bars connecting the frames, and turning the frames down into recesses in the apron (Wegmann 1899:151-152).

Another means of emergency closure employs a series of wickets housed in slots in the lock sill. In its raised position, a wicket forms a modified A-frame. A handling derrick maneuvers the wickets. A disadvantage cited by C.E. Blee was that the wickets were continually immersed in water when stored and were therefore subject to severe corrosive action. In addition, the slots were subject to silting. Emergency closure wickets were installed at the Montgomery Locks on the Ohio River, as well as at Pickwick Landing Dam on the Tennessee River (Blee 1951:851-852).

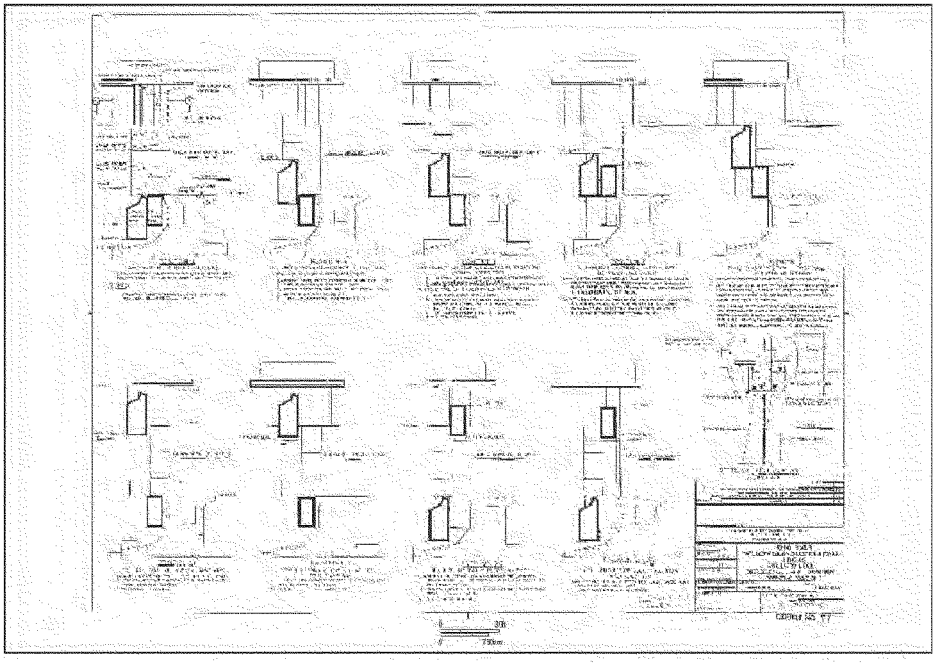
The Emsworth, Montgomery and Dashields 110-foot chambers have emergency closures consisting of Boulé dams located at the upper ends of the lock. This dam consists of trestles and bulkheads set up by a derrick crane. The trestles, with 11 feet 8 inch centers, are raised parallel to the lock walls from their trenches in the bottom of the lock chamber by a derrick crane. The trestle prop is hinged at the bottom, and the derrick is rigged with an operation chain to which the trestle chains are attached by clamps. The trestle is then raised into place bringing the next trestle's chain with it. Aprons, which serve as walkways, are pin-connected to the tops of the trestles. Maintenance closure gates, located at the lower end of the main chamber, consist of Poirée dams at both Emsworth and Montgomery. Prior to 1982, the Dashields lock also employed a Poirée dam. In 1982, this maintenance closure was replaced with a bulkhead system, identical to that used at Hannibal locks (USACE-Pittsburgh 1971:4; USACE-Pittsburgh 1972a:2-3).

The auxiliary lock chambers at Emsworth, Dashields and Montgomery each use needle dams for upstream closure. The original needle dams consisted of a coffer beam with trestle and timber needles. The present closure system uses steel needles. A derrick crane places a coffer beam into two slots cut in the walls. The coffer beam is then used as a brace for trestles that are lowered into place upstream of the beam and rest on a sill at the bottom of the chamber. The tiber needles were used to connect the box trestles to the coffer beam and each other, and the boxed trestles were edges with wood timbers for better sealing. Three sets of beams and needles were stored at the Pittsburgh district's warehouse and were used for all the 56-foot chambers in the district. Maintenance closure of all three auxiliary locks is accomplished by Poirée dams located at the lower ends of the locks (USACE-Pittsburgh 1971:3-4; USACE-Pittsburgh 1972a:2-3).

Many of the locks constructed as part of the post-World War II modernization program used a newly developed system of emergency gates. Submergible double-leaf lift gates are employed. These gates were designed to be operated under maximum head and unrestrained flow through the lock chamber (Figure 1-35). The upstream leaf, consisting of horizontal girders and a skin plate, is designed for use as a movable sill. The downstream leaf, also constructed of horizontal girders and skin plate, is designed for operation through flowing water (USACE-Huntington 1976:7). When not in use, both leaves were lowered to prepared beds behind a concrete sill across the upper lock entrance above the upper miter gates. Hoisting equipment is provided (Bruce et al. 1957:1239-10). At Meldahl locks, the two leaves are each 21 feet high and are designed so that only the downstream leaf needs to be operated when the river is at or near normal upper pool. When the river is above normal upper pool and the emergency gates are to be closed through flowing water, the downstream leaf is always raised first (USACE-Huntington 1969:3).

At Meldahl locks, the hoisting equipment is located in structures raised above the lock walls. The hoist consists of a double-grooved rope drum driven by two stages of open spur gearing, a herringbone or helical gear reducer, and an electric drive motor with brake. The rope drum has three layers of rope. The hoist components are mounted on a structural steel frame that is anchored to a concrete structure on the lock walls (USACE-Huntington 1969:4).

Figure 1-35. Willow Island Locks and Dam. Locks. Auxiliary Lock. Emergency gate hoist machinery operating positions (U.S. Army Engineer District, Huntington 1968). (From USACE-Huntington 1976).



Should one miter gate be standing open and the other be opened by a navigation accident, the emergency gate can stop flow through the lock chamber, thus saving the navigation pool and allowing navigation to continue through the other lock. The emergency gate can also function as an upstream bulkhead which, together with the downstream bulkheads, will permit dewatering of the lock and repair of damaged miter gates (USACE-Huntington 1969:2).

By 1964, vertical lift emergency gates were in use at Greenup, Meldahl, Markland, McAlpine as well as Barkley Lock on the Cumberland River and Eisenhower Lock on the St. Lawrence River. New Cumberland Locks used steel bulkheads for emergency closure as did Pike Island (Richardson 1964:81, 99). Subsequent projects installed vertical lift emergency gates at Racine, Willow Island, and Robert C. Byrd locks, as well as Winfield locks on the Kanawha River (McCoy 2000).

Maintenance closure of the locks for most of the locks is accomplished in two basic ways: Poirée dams and lock bulkheads. For example, at Racine locks a set of bulkhead sections are used for closure. These bulkheads are assembled in the lock wall bulkhead recesses, on the sill provided downstream from each of the lock service gates, and are placed by floating plant (USACE-Huntington 1971:4). The Meldahl lock bulkhead consists of 5 six-foot high sections creating a damming height of up to 30 feet. A similar lock bulkhead is used for Greenup Locks. The bulkhead can also be used as the downstream closure in gate bays of the dam (USACE-Huntington 1969:4). At Belleville locks, the bulkheads are placed by a crane operating on the crane bridge extending continuously over both locks and the dam. The Belleville bulkheads are multi-purpose, used for emergency closure of the lock chamber, as a means of skimming drift and ice accumulation from the upper lock approaches, and for dewatering the lock chamber for

maintenance and repair. The same bulkheads are intended for use at Racine, Belleville or Willow Island (USACE-Huntington:Belleville: 3).

The dam system employs metal trestles that collapse sidewise onto the dam foundation at high water. At low water the trestles are raised and boards laid across for workers to walk on. The workers lower wooden boards, known as needles, to rest on the upstream face of the trestles, forming a dam (Kemp 1991:2).

In his study of lock closures, C.E. Blee noted that in those locks equipped with rolling lock gates, maintenance of these gates was made possible by use of a floating coffer or caisson and a temporary navigation gate. He noted:

> having a broad base and a vertical access superstructure. When sunk in place over a gate track, it extends halfway across the lock. The temporary gate is used across the other half of the opening. By pumping out the central part of the caisson, access is provided to that part of the gate track covered by the caisson. The other part can be inspected and repaired by reversing the position of the caisson and temporary gate. When the caisson is on the land side of the lock chamber, it bulkheads the gate recess, thus permitting work on the gate. The caisson and temporary navigation gate are handled by suitable derrick boats. Navigation through one side of the lock is maintained by handling the temporary gate (Blee 1951:857-858).

Bulkheads are generally used for emergency closure of a dam gate bay. At Racine Dam, four similar sections are latched together to form the bulkhead. Each section is 110 feet long and 8 feet 6 inches high giving a total damming height of 34 feet above the sill. At Meldahl Dam, the bulkhead sections measure 100 feet long by 9 feet high. Because the bulkheads work as a unit, the result is basically a vertical-lift type gate.

The bulkhead sections are of welded construction and are fabricated principally of low allow steel. Each bulkhead consists of an assembly of three open horizontal trusses with lateral bracing and an upstream skin plate. Vertical tee stiffeners support the skin plate. All bulkhead sections are designed for the bottom position in the assembly for complete interchangeability. Latching devices are provided at each end of the bulkheads for latching the sections together.

Bulkhead sections are placed in the dam gate bays by a traveling bulkhead crane electrically powered from a trolley contacting conductors on the bridge beam. A lifting beam supported by the crane hoists handles placement of the bulkhead sections (USACE-Huntington 1971:8). The bulkheads, each weighing 90 tons, can be picked up and transported from their stored position in any of the gate bays and placed in a gate bay selected for closure (USACE-Huntington 1969:12). This design was used at Belleville, Greenup, and Captain Anthony Meldahl complexes (USACE-Huntington 1971:7).

The Gallipolis Dam uses a different means of placing bulkheads. The upstream emergency dam consists of seven emergency bulkhead units which are lowered into place by a floating crane unit and which rest on the upstream edge of the roller gate sill and the upstream emergency bulkhead supports. Each of the seven units consists of two trusses approximately 128 feet in length and four feet high, connected by lateral and transverse bracing, and plated on one side. Timber seals are provided where the bulkheads contact each other (USACE-Huntington 1970:5).

Power Systems

When the Davis Island Lock and Dam on the Ohio River was being planned in the 1870s, the Board of Engineers had suggested that steam engines be used to pull the lock gates and to open and close emptying and filling valves. Major W.E. Merrill preferred, instead, to use a turbine to provide power for lock operation. In his history of the Davis Island Lock and Dam, Leland Johnson described the operation of Merrill's system:

> When the turbine was spinning, it would power a pump to move water from the river into two wooden tanks on trestle towers of the sort used to replenish locomotive boilers. The system included a 25-inch-diameter turbine placed in the lock river wall, a pipe across the bottom of the lock to the pump, a pipes from the pump to the top of the water tanks. The tanks provided a reserve of water to spin turbines at each lock gate, the water dropping through pipes some sixty-two feet from the tanks to the turbines. As a redundant back up system, he also purchased a portable steam engine, albeit reluctantly. "One of my chief objections to steam," he told William Martin, "is the fear that at night, when there is little travel, the fireman will fall asleep & explode his boiler or let his steam run down so low as to be insufficient to do the required work." His fear proved well founded; several years later the steam engine boiler exploded, killing the dam tender (Johnson 1985:90-91).

At Davis Island, the steam for operating the lock gate engines was generated in a boiler at the lower end of the locks, while the steam for the upper gate engine was piped about 600 feet to the engine. Because of trouble with condensation in the long steam line, a boiler was installed at the upper gate recess.

At the subsequently constructed locks, potential waterpower available when the dam was up was not used. Power for operating the gates and valves was instead obtained from coal burning steam plants or from gas engines at locations where natural gas was available. Machinery and boilers for lock and dam operation were located in a powerhouse (Figure 1-36). In the earlier locks, compressed air was used for operating the filling and emptying valves, working through jacks, racks and sectors connected to the valve stems. Eventually, difficulties experienced with the use of air led to the substitution of an oil-hydraulic system for operating valve jacks.

At Lock No. 6, the boilers were originally located in the powerhouse, opposite the middle of the lock. Steam was piped about 300 feet to each gate engine, and condensation problems resulted. Compressed air was first used to assist in the moving of the beartrap gates. With the installation of a larger compressor, compressed air was used to power the gate engines (Sibert 1908:1199).

The original configuration of the Lock No. 6 power system is shown in Figure 1-37. The powerhouse was equipped with boilers, electric generator and steam pump for operating hydraulic jacks. A three-foot diameter pipe conduit extended from the powerhouse and subsequently branch off in several places. A three-inch steam line contained in a 12 inch by 22 inch conduit extended the length of the land wall of the lock to steam engines that provided power for operating the rolling lock gates. Four way valves were attached to each steam engine to control the jacks that operated the filling and discharge valves in the river wall. Pipes extended beneath the floor of the center of the lock to connect to pipes extending the length of the river wall. Two jacks mounted in the pipeline synchronized the operation of these valves.

An anonymous writer in the Corps of Engineers' *Professional Memoirs* suggested an auxiliary power system in which two 50 inch turbines would run an air compressor to operate the lock and dam during breakdowns in the main power plant (Anonymous 1909a:422-424). It is uncertain whether this proposed scheme was used at any of the numbered locks.

Figure 1-36. Power House for Ohio River Dams. Longitudinal section of power house (Pittsburgh District, U.S. Army Corps of Engineers 1905). From Cartographic Branch, National Archives.

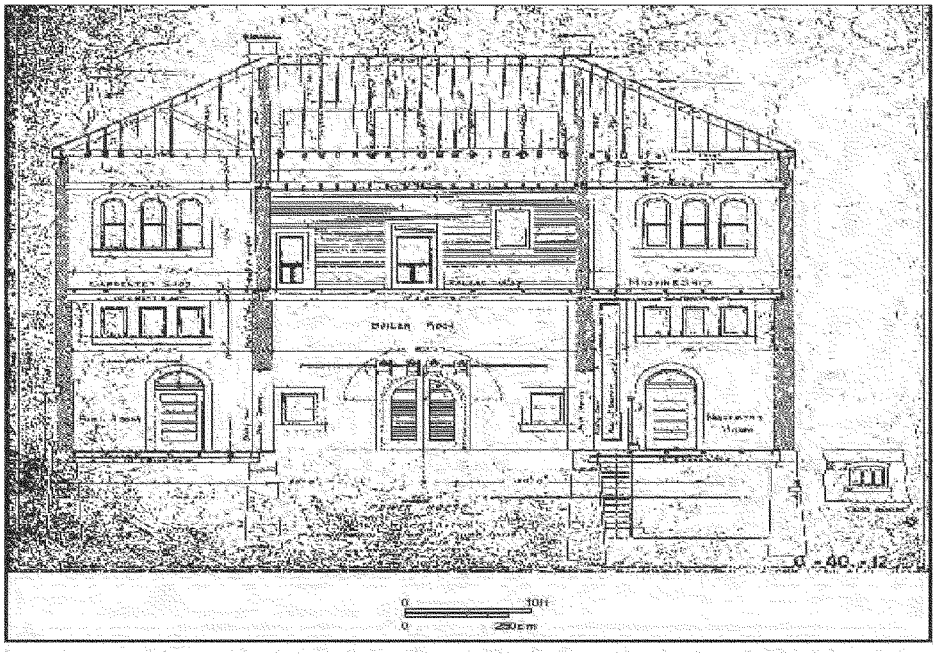
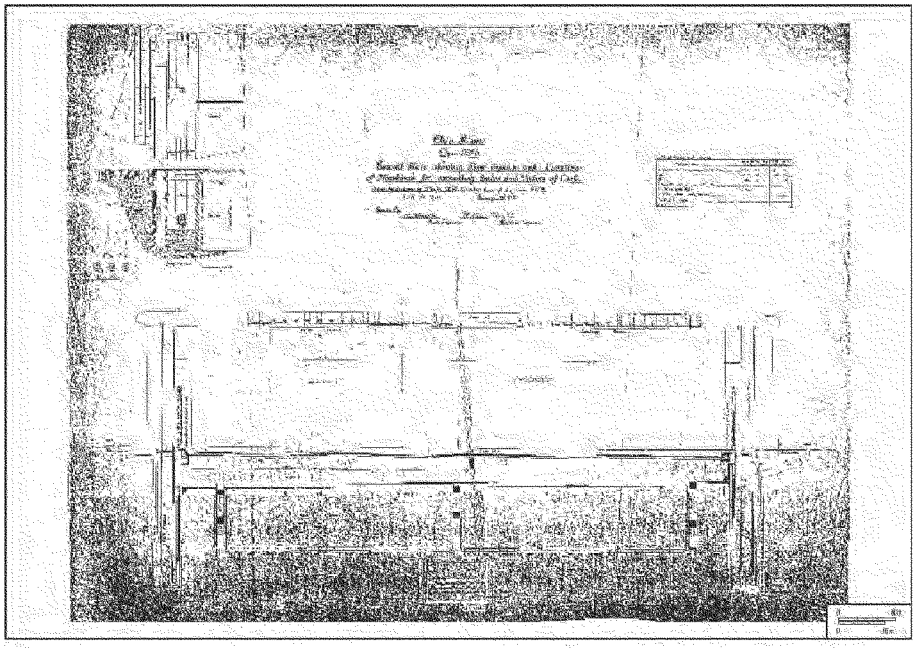


Figure 1-37. Ohio River Dam No. 6. General plan showing pipe system and location of machines for operating gates and valves of lock (Venable 1900). From Cartographic Branch, National Archives.



Subsequent locks used a power system consisting of two Westinghouse, three-cylinder, vertical, gas engines that operated on natural gas, and two-chain-driven, Blaisdell, two-stage air compressors. The operation of the beartraps was facilitated by air forced into the lower leaves, directly from the air tanks. The gate engines were also operated by compressed air. The filling and emptying valves were operated by liquid pressure; the pump was operated by compressed air (Sibert 1908:1199).

The locks built between 1914 and 1930 had a water turbine installed on the river wall that served as a primary source of power. A land power plant was also provided as an auxiliary and was equipped with a semi-diesel engine (Kutz 1930:434). For example, the original operating machinery of Emsworth locks, installed in the 1920s functioned by compressed air supplied by a turbine-driven compressor on the land wall. In 1968, this power source was replaced by a hydraulic system (USACE-Pittsburgh 1971:2).

Many of the locks and dams on the Ohio were constructed with low-head Francis turbines of 30 to 150 hp (20-125 kw) intended for use as standby power sources and where the head permitted, as primary power sources. Some of these turbines directly operated oil pumps. By 1940, commercial electric power became generally available, and turbines were rarely used. Steam plants were replaced by diesel engines or diesel-electric generators (Engineer School 1940:380).

The Deadman Island Locks and Dam were built for waterpower operation. The complex was equipped with three turbines, the independent intakes of which opened directly through the river wall at the upper pool. In addition to the turbines, the equipment included oil pumps and accumulators. The latter devices, operated in conjunction with each pump, provided the additional power needed for gate operation. Casey described the operation of the turbine system:

> The power turbines are of the vertical, open flume, wicket gate type. Two of these turbines operate vertical triplex pumps giving 250 pounds pressure in the oil lines for lock operation. The third, through a vertical shaft and bevel gearing, operates a 25 k.w. d-c horizontal electric generator for power for lighting and operating electrical facilities such as capstans. For heads of from 10 to 14 feet between upper and lower pools, either turbine will drive either pump. For heads less than this, both turbines may be connected to drive either pump....
>
> When power is used, the turbine is brought into operation by the opening of the turbine gates.... The turbine remains in operation all the time power is being used and until the accumulator is then filled, when it stops automatically. This power is transmitted to the gate and valve-operating cylinders on both locks by high pressure oil lines (Casey 1929:447).

A vertical fire tube boiler was installed to provide reserve power in the event that the turbines were out of operation.

By 1940, lock operating machinery was generally of the electrical or hydraulic type. Electrical equipment had the advantage of low initial cost, high efficiency, lower maintenance cost, and dependability, Hydraulic operation of valves and gates has the advantage of elasticity, avoiding overloads on the power units and shocks and jars on the structures themselves. There are few moving parts, and individual jacks in a large system may be controlled by one control valve. This last feature was especially necessary on the Ohio, where 34 separate butterfly valves in as many lateral culverts had to be operated at one time. In addition, hydraulic machinery is not damaged by submersion, a major point in its favor on the Ohio River (Engineer School 1940:388-389).

Presently, the lock machinery at all Ohio River locks is operated by an electrically powered hydraulic system similar to that used at most locks on both the Monongahela and the Allegheny rivers.

Construction Techniques

In his history of the Louisville District, Corps of Engineers, Leland Johnson noted the difficulties contractors faced in lock and dam construction on the Ohio River:

> Floods frequently arrived unexpectedly, topping cofferdams, injuring equipment, destroying completed work, and burying the work under tons of silt. Work was ordinarily suspended during bad weather and high water season; on this account, contractors were often allowed a certain number of "fair working days" to complete a project. Delays and accidents beyond the control of the contractor were usually considered ample reason for extending contract time, but contractors assumed all risk to the equipment and unfinished construction (Johnson 1975:182).

The original Louisville and Portland Canal, the earliest major engineering project on the Ohio River, was excavated using hand tools, oxen-drawn plows, and scrapers dragged by horses. Excavated materials were removed in wheelbarrows and horse-drawn carts. Gunpowder was used to facilitate rock excavation (USACE-ORD 1979:17).

Lock Materials

The earliest locks in the Ohio River Valley were constructed of cut stone. By the twentieth century, all of the locks with the exception of the steel gates were constructed of concrete. Given the huge masses of concrete involved, design and control of the concrete was an item of major importance. The design of the mix for the modern locks represented a combination of laboratory and field practice. Lieutenant W.E. Potter described the procedure used at Montgomery Island Locks:

> Extensive analyses were run on the aggregates for both physical characteristics and grading. After ascertaining that the aggregates were physically satisfactory, a series of sieve analyses were run. The aggregate proportioning was determined by trial...
>
> The aggregate proportion which gave the least voids was then used in the selection of sand percentage. Sand was added in quantity equal to the voids in large aggregates, plus 5 per cent. Cement to the amount of five sacks per yard was added...and several hand mixes were made and changes were made in the sand content until the best quality concrete was obtained. This is the true laboratory mix, but due to the large size of the aggregate, it does not give a true picture of the mix as used in the field. Further work is then transferred to the field where full size batches (usually 2-yard) were made....Since the mix was

Figure 1-38. Typical section through Ohio River type box cofferdam (Dravo 1947).

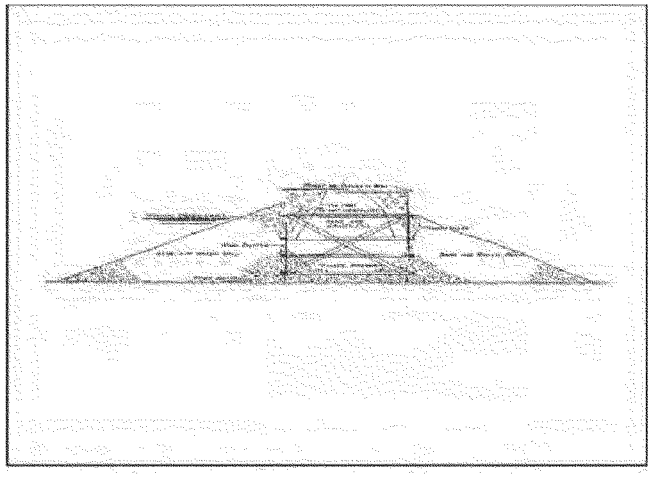
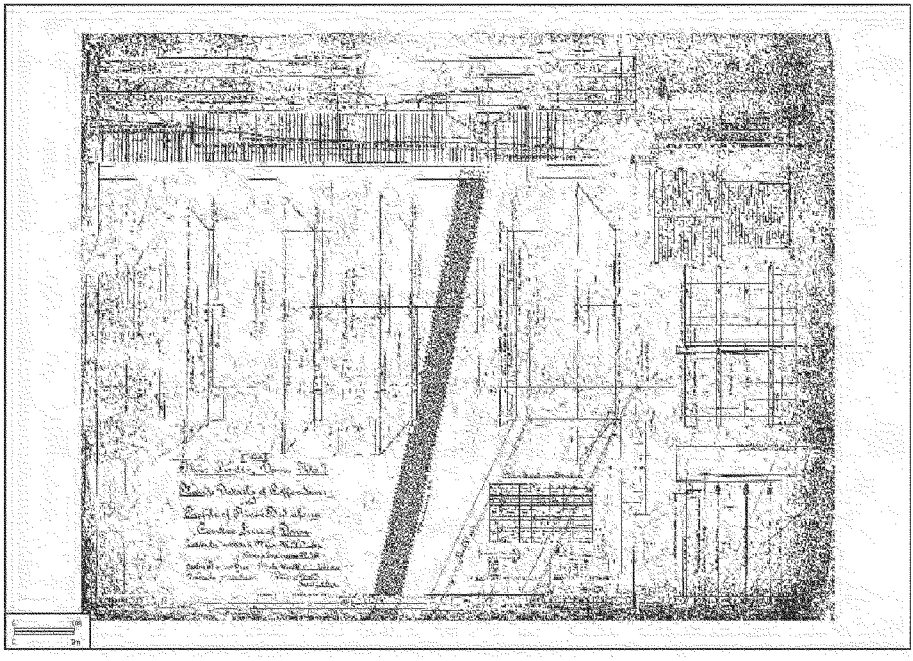


Figure 1-39. Ohio River Dam No. 2. Plan and details of cofferdam (Bowman 1900). From Cartographic Branch, National Archives.



approximately correct when it left the laboratory, only minor changes were necessary in the field (Potter 1935:105-106).

Cofferdams

The first cofferdams used in American lock and dam construction consisted of a dike of compacted earth. These cofferdams were sometimes improved by installation of a central cutoff wall of wood piling, and occasionally by the use of riprap on the exterior to reduce scour. Such primitive cofferdams were subject to major damage during high water periods.

Another early method of cofferdam construction involved the use of a crib of interlaced timbers filled with rock to provide stability and sheeted on the outer face with tightly engaged wood sheeting. These cofferdams tended to be reasonably durable during periods of high water (Jansen 1948:26).

A third type of cofferdam was developed for early Ohio River construction and was therefore called the Ohio River type box cofferdam (Figures 1-38 and 1-39). This structure consisted of two rows of wood sheeting spaced 16 to 20 feet apart with timber wales on the outside held together by steel rods passing through wales and sheeting (Jansen 1948:27). A typical box cofferdam employed for Lock and Dam No. 53 was described in a 1928 article in *The Military Engineer*:

> An ordinary box-type cofferdam, 30 feet deep, was used to enclose the lock chamber. The cofferdam was held together by ½-inch steel rods and was braced laterally by 6- by 8-inch wales. Two-inch sheeting was placed on the sides of the wales (Suppiger 1928:513).

This cofferdam was placed on the river bottom with suitable protection against erosion. If rock was fairly close, a trench could be dredged out so as to set it on rock. As usually designed, the cofferdam was not a self-sustaining structure but required extensive banking both inside and out to give it stability. This banking also helped to prevent seepage (White and Prentis 1940:151-152).

Carl Jansen described construction of the Ohio River box cofferdam:

> ...the first operation was to assemble on a barge a framework consisting of the wales, rods, spreaders and bracing, with one vertical sheet of planking at each tier of rods. As the barge moved forward the structure was allowed to settle into its place on the river bottom. The remaining spaces between the rods was then sheeted on each side with 2- or 3-in. planks resting on the river bottom, the size of the planks depending on the depth of the cofferdam, which was filled immediately as near as possible to the top. A berm was then placed on both the inner and outer sides. Sand and gravel as dug from the river provided the best kind of fill and were ordinarily used. In most cases a decking was placed over the top, composed of either 2-in. plank, or a layer of concrete 4 to 6 in. thick, to prevent washing out of the cofferdam fill during periods of high water. It was often necessary to place riprap around the corners to prevent scour inasmuch as stages up to 50 ft. could be expected to overtop any cofferdam in the Ohio River (Jansen 1948:28).

The specific techniques used to construct the Lock 53 cofferdam were described by E.W. Suppiger:

> Dredge and derrick boats excavated along the line of the lock walls, and the excavated material, sand and gravel, was used to fill the cofferdam. After the cofferdam had been sunk, the water was pumped out. The pump boats settled to place on pile foundations as the pumping advanced. Two 15-inch centrifugal pumps were used on each of the boats, with steam supplied by three 150-horsepower marine boilers. An air compressor and a complete electric-lighting plant for night illumination were also part of the equipment. Work on the dam was carried on twenty-four hours per day for seven days per week.
>
> As the water inside the cofferdam fell, the railroad tracks, which had been built previously, settled to place...Four pile-driving boats were required to drive the wood and steel piles (Suppiger 1928:513).

The Ohio River box cofferdam had several disadvantages. Because of its design, the cofferdam was necessarily located a substantial distance from the enclosed work. The berm was constructed with a slope of 1 to 2 or 1 to 3 in the river near Pittsburgh and with a slope of 1 to 5 or 1 to 6 further downstream where the river bed contains more sand and gravel (Dravo 1947:7). The cofferdam also necessitated the provision of two types of plants on each job, a floating plant for use on the outside and for building the cofferdam itself, and a land plant for work inside the

cofferdam. This type of cofferdam also occasionally suffered substantial damage from high water (Jansen 1948:28).

To address these disadvantages, several new types of cofferdams were developed. One type was the internally braced interlocking steel sheetpile cofferdam (Figure 1-40). After several unsuccessful attempts, this type of cofferdam was successfully used for the first time at Dam No. 23 on the Ohio River. This type of cofferdam permitted the use of floating equipment almost exclusively. The equipment could be removed quickly if flood or ice threatened (Jansen 1948:28).

The cofferdam used arch web steel piling with timber sets at sufficient frequency to provide adequate strength. The cofferdams at Dam No. 23 were built in lengths of 160 feet with an additional transition section of 16 feet. Each cofferdam was 42 feet wide. Dravo Corporation spokesmen noted that although one rise of the river filled the cofferdam completely with chunks of ice and twice the coffer was half filled with river deposit, the steel pile cofferdam held (Dravo 1947:16-17).

At the same time when new cofferdams were under development increased use was made of caissons (Figure 1-41). For example, the contract for Dam No. 32 was awarded to the Dravo Corporation in 1922. The dam was to be constructed using pneumatic caissons. When the first caisson was sunk to the level where rock was supposed to be foundation, there was no rock, only compact sand and gravel and boulders. To accommodate site conditions, Dravo constructed the entire dam with the exception of the beartraps with steel floating caissons sealed under compressed air (Miller 1950:28-29; See Figure 1-38). These thirteen caissons were designed and assembled by Dravo in Pittsburgh and towed to the dam site, 372 miles downriver. The size of

Figure 1-40. Typical section through a steel sheet pile cofferdam (Dravo 1947).

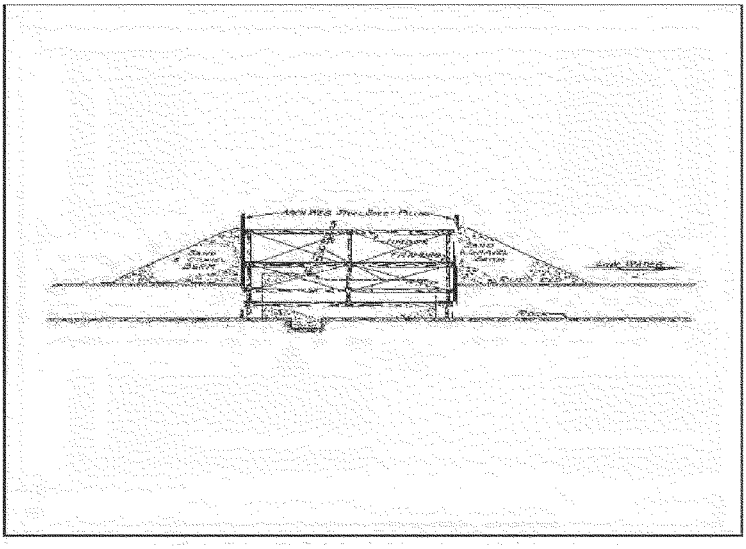


Figure 1-41. General layout of caissons and cofferdams. Ohio River Lock and Dam No. 32 (Dravo 1947).

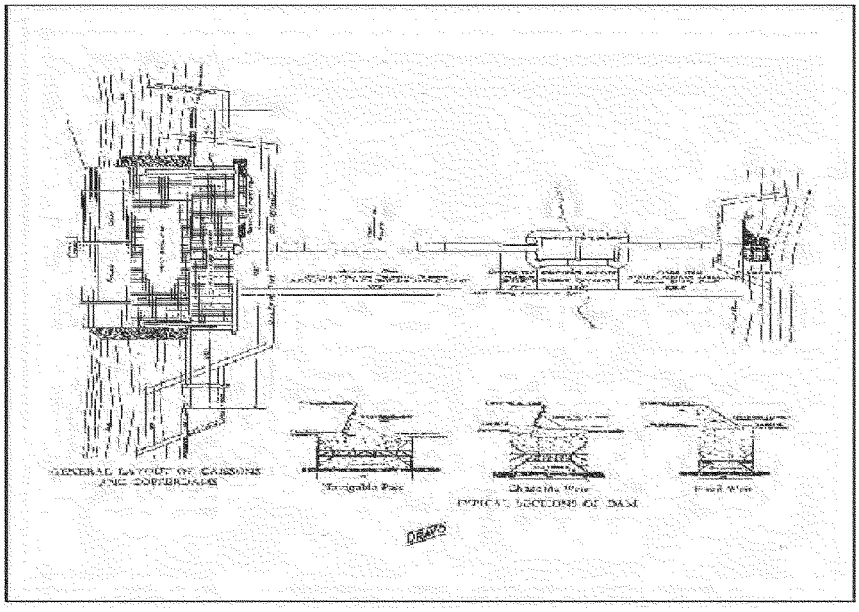


Figure 1-42. Section through navigation pass caisson (Trippe 1924).

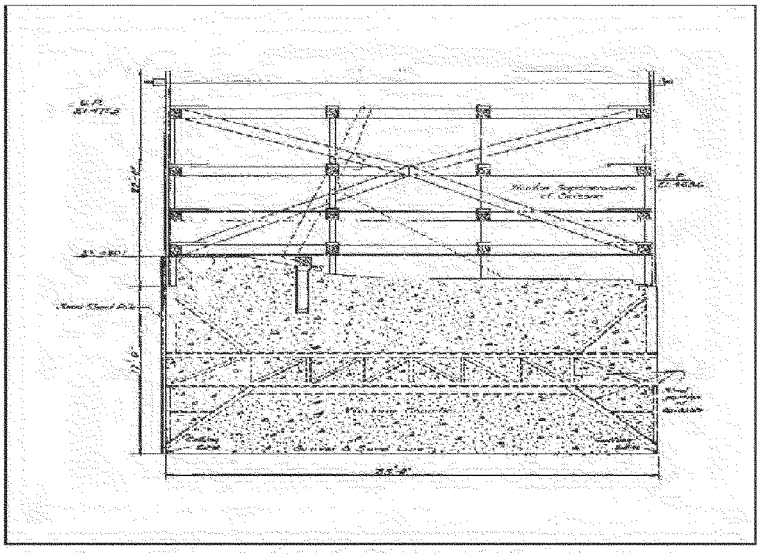
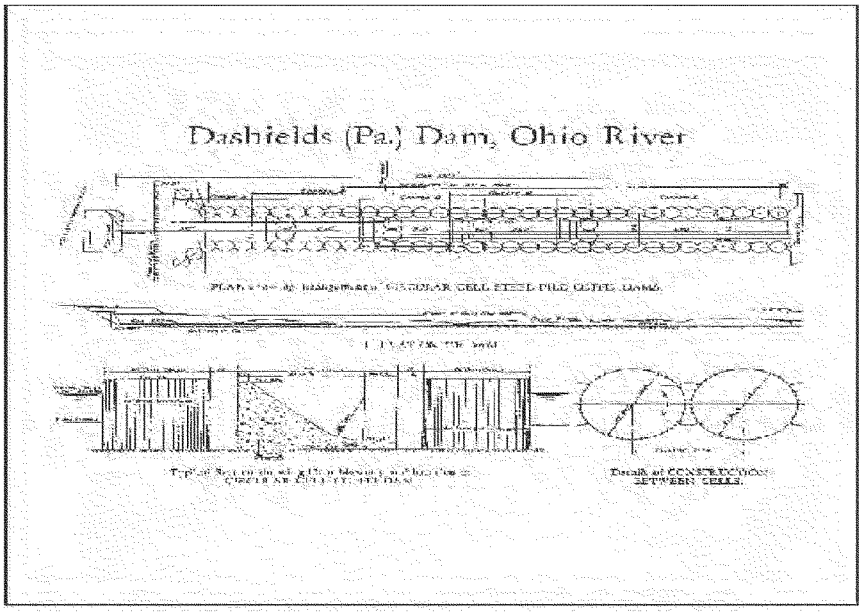


Figure 1-43. Plan, typical section, and details of circular cell steel pile cofferdam used at Dashields Dam (Dravo 1947).



the caissons varied from 35 feet by 75 feet for one section of the navigable pass to 20 feet by 111 feet 4 inches for the fixed weir (Dravo 1947:19; Figure 1-42).

The first caisson was sunk adjacent to the river wall of the lock. Excavation within the caissons was done by open dredging until the caisson had been sunk to an elevation supposedly near rock. Air locks were attached to the dredging tubes, compressed air was supplied, and the sinking continued through compact boulders and gravel. In the absence of rock, the first two caissons were carried down to a fire clay strata and then sealed (Dravo 1947:20). The pneumatic caissons were sunk independently along the lines of the dam with a concrete seal placed between sections using the tremie method. This approach enabled the use of a relatively small plant and made all parts of the work accessible to floating equipment (Jansen 1948:28).

On Dam No. 32, caissons were impractical for construction of the piers and beartrap weirs. The shallow foundations of the beartrap piers and the absence of rock on which to found the caissons did not permit the addition of sufficient weight to hold the caissons in place (Dravo 1947:20). This led to the use of a cellular type of interlocking steel cofferdam in which the bases of the piers and weirs were placed by submarine concrete bucket. Steel pile cells were filled with sand and gravel to provide stability. This type of cofferdam allowed floating equipment to handle practically all the work including the erection of the beartrap steel (Jansen 1948:28).

The first use of a cellular steel cofferdam for the entirety of dam construction occurred at Dashields Dam (Figure 1-43). The cellular steel cofferdam has been developed to raise the battleship *Maine* in Havana Harbor. (Miller 1950:54) and was first successfully used in the construction of the Black Rock Lock on the Niagara River in Buffalo (Jansen 1948:29).

The Dashields Dam was constructed in 1928-1929 within five sections of cofferdam, using cells 40 feet in diameter, spaced 42 feet from center to center. The 2-foot spaces between the cells were closed by two short arcs of sheeting connected to T-piles in the walls of the cells. Five sections of cofferdam each enclosed an area 80 feet wide and varying from 210 to 498 feet in length (Dravo 1947:29-30). Carl Jansen discussed the success of this cofferdam at Dashields:

> The Dashields cofferdam was looked upon by some as an experiment, uncertain of success. Nevertheless, actual experience proved its practicality. The cofferdam, which was driven to rock, provided for a 40-ft. head of water and permitted continuous work within the cofferdam until the river exceeded a level 8 ft. above normal. Full-revolving whirlers mounted on top of the concrete-decked cofferdam had uninterrupted access to the work (Jansen 1948:29).

The cofferdam was exceptionally watertight. After unwatering the 80 by 489 foot section under a 32 foot head, one 15-inch centrifugal pump kept it dry (Dravo 1947:30). Subsequent dam construction projects involved development and adaptation of this type of cofferdam.

As a result of cofferdam failure during the construction of the Cannelton and Uniontown locks and dams, the Stage 1 cofferdam for Hannibal Dam was redesigned during construction. It was anchored, using prestressed cable anchors more than 45 feet long grouted into rock and using concrete thrust blocks placed against the base of steel sheet pile cell walls. In addition, 63 pressure relief wells were installed at the base of the cofferdam cells and frequent testing of the underlying clay was made.

The Stage II cofferdam was also modified based on experience at Cannelton and Uniontown. The distance between the upstream and downstream arms was increased and the cofferdam was strengthened by berming the inside of the cofferdam 8 to 12 feet in height behind a seepage control wall. Instrumentation was installed to monitor site conditions (USACE-Pittsburgh 1973:5).

The contractor for Newburgh Locks and Dams, whose construction began in 1965, implemented an innovative cofferdam technique because bedrock lay a hundred feet below normal river level. A complex of subcoffers were used inside the main cofferdam for the pier foundations. The large cofferdam was constructed and dewatered and then more cofferdams were built inside to get deeper into the riverbed with safety. One of these cofferdams was in a unique figure-eight configuration to eliminate the need for internal bracing. Additional pier stability was gained by the first Louisville District use of prestressed rock anchors, steel cables up to 123 feet in length (Johnson 1984:41).

One of the engineering problems faced by Louisville District staff was building locks and dams on a sandy foundation, characteristic of the riverbed of the lower Ohio River. The solution they developed consisted primarily of driving round timber piles, generally about thirty feet long, to the rock substrata and building the concrete foundation for the lock or dam structure around the tops of the piles. Wooden and later, interlocking steel sheet piling, was driven down on the upstream side of the structure to form a curtain protecting the foundation. Riprap stone was placed on the downstream side to prevent scour and further stabilize the structure (Johnson 1975:183).

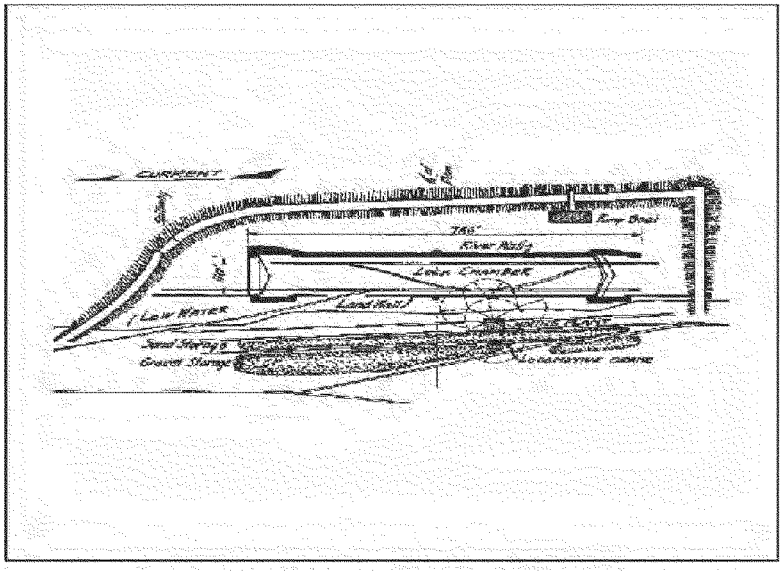
Construction Methods

To transport materials to and from the cofferdam construction sites, cableways were generally used. For example, at Lock and Dam No. 37 near Cincinnati, Ohio, two cableways of 300-ft. span were erected. These cableways were used to remove excavation material, deliver concrete, handle material, and erect the steelwork of the rolling lock gates. All work on the dam was done by stationary derricks in the pit and at the concrete mixing plant and by traveling derricks that ran on the cofferdam (Anonymous 1909b:238).

A *Military Engineer* article by Captain W.F. Heavey described the concrete mixing and placement at Lock No. 45. The project included pouring of 40,000 cubic yards of concrete to form two walls, a land wall of 1,100 feet and a river wall of 785 feet. Construction at this lock was accomplished using a movable gravity plant for concrete mixing and distribution. Heavey described the track system:

> The mixing plant moves on two standard gage tracks laid on 20-foot centers, the one next to the lock being six feet lower to conform to the slope of the bank and thus reduce the grading necessary for the road-bed. A third track was laid on top of the bank, and 30 feet from the upper mixer track, for a locomotive crane which is used for feeding the sand and gravel bins from storage piles on the bank....The upper mixer track is connected to the yard tracks thus allowing the cement in the railroad cars to be moved, as received, directly to the mixer and unloaded on an inclined belt conveyor which carries the cement to the mixing platform of the concrete plant (Heavey 1924:144; Figure 1-44).

Figure 1-44. Layout of lock coffer, Dam No. 45, Ohio River (Heavey 1924).



The mixing plant, designed by engineer H.G. McCormick, used materials already on hand. It consisted of a wooden tower, 50 feet high, supported by an A-frame, resting on a platform of I-beams that rested on a standard flatcar. The lower lifts of the river walls, the upper and lower miter sills, the land wall, and sections of the guide walls, were poured directly from the plant by chute. The concrete for the upper lifts of the river wall needed to be rehandled by a locomotive crane and bottom dump buckets (Heavey 1924:145).[4]

Booth & Flinn, the contractors for the Montgomery locks introduced three long-span cableways of 1,510 feet in their construction site (Figure 1-45). The firm had pioneered the use of these long-span cableways in their early George Westinghouse Bridge construction near Pittsburgh. 150 foot high head towers and 110 foot high tail towers supported the Montgomery cableways. Each had a capacity of 25 tons. The cableways handled much of the excavated material and backfill, placed all of the concrete, aided in erecting forms, and transported miscellaneous supplies and materials. A central mixing plant was erected on the cofferdam which discharged concrete into the five-yard cableway buckets set on flat cars on a dinkey line (Anonymous 1934:515, 518; USACE-Pittsburgh 1972b:9).

Lieutenant W.E. Potter's article on Montgomery Locks provided additional information about the construction procedures. Describing concrete mixing, he wrote:

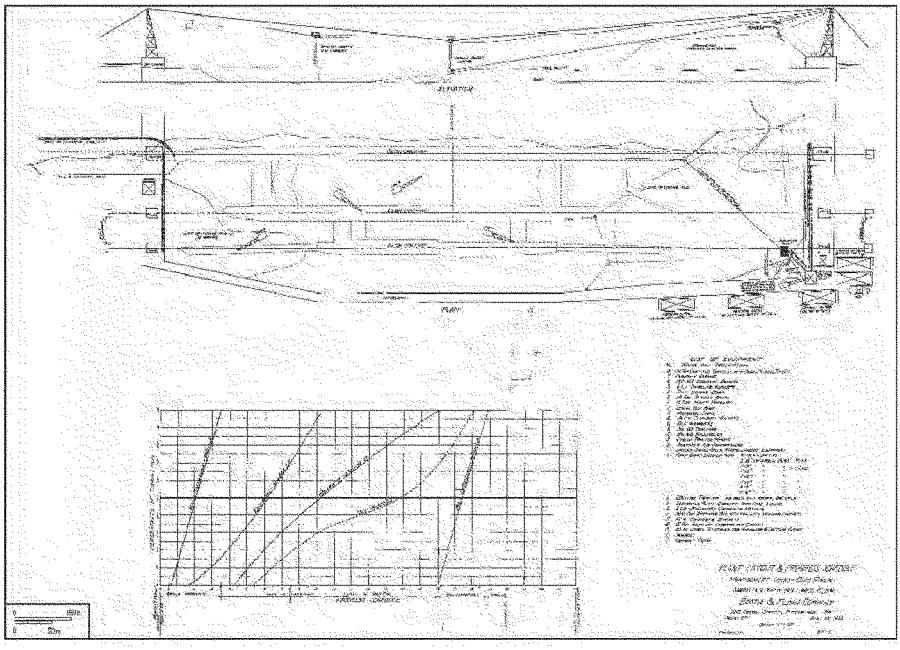
> The aggregates were delivered in barges which were anchored below the lower arm of the cofferdam. They were transferred as needed from the barges to the bins over the mixers by means of an American Whirley. Cement was delivered by barge and was air-blown to its bin over the mixer.
>
> The bin batchers and mixers of Blaw-Knox construction were housed in one structure, centrally situated on the lower arm of the coffer. Bins for the three aggregates and cement were in the upper part of the structure and were arranged to dump into the proper weighing hoppers....
>
> The mixer unit was composed of two horizontal 2-yard Rex mixers, end dumping. Mixing time was specified as 2 minutes for the 2-yard mix. An electric clock regulated the mixing time and prevented dumping before the specified time had elapsed (Potter 1935:106).

Montgomery Locks used two types of concrete forms, the rolling gantry and panel types. The gantries were steel structures, approximately 50 feet high, capable of forming a single monolith (Potter 1935:106).[5]

The Markland Locks and Dam construction project was notable in the amount of construction activity that took place on water. Bulk materials for construction were moved to the site by barge. In addition, three derrick boats and a mixer boat were used to drive piles and place concrete for the guide walls (Anonymous 1958).

[4] The Heavey article cited in the references describes the concreting procedure at Lock No. 45 in detail.
[5] The Potter article cited in the references describes the concrete mixing and placing procedure used at Montgomery Locks in complete detail.

Figure 1-45. Montgomery Locks – Ohio River. Plant layout and progress schedule (Booth & Flinn Company 1932). From Cartographic Branch, National Archives.



HISTORIC ENGINEERING EVALUATION

This report summarizes the engineering characteristics of all the navigational structures of the Ohio River Mainstem system. To determine the engineering significance of these structures, they are compared to those of other similar navigational systems. The systems chosen for comparison are the Allegheny River, the Monongahela River, the Kanawha River, and the Mississippi River.

The Allegheny River navigation system consists of eight single lock and dam structures. All locks are 360 feet in length and 56 feet in width. All of the dams on the river are fixed crest concrete weirs. The oldest of the locks opened in 1927, while the most recently constructed opened in 1938.

The first lock chamber of the Monongahela River locks, Lock No. 1, was completed under contract to the Monongahela Navigation Company in 1841. Eventually, the MNC system consisted of seven lock and dam complexes. The last of these, MNC Lock and Dam No. 7, was completed in 1883. The first locks measured 158 feet long and 50 feet wide while the last of the locks measured 277.5 feet long and 56 feet wide. Beginning in the late nineteenth century, the U.S. Army Corps of Engineers began to rebuild existing locks and extend the navigation system further upriver. The system presently consists of nine navigational complexes. Lock sizes range from 360 feet long by 56 feet wide to 720 feet long and 110 feet wide. Construction on the earliest surviving complex, No. 2, was originally completed in 1906. Its lock chambers were later rebuilt. Lock construction at the newest complex, Grays Landing, was completed in 1993. Monongahela River dams include both low concrete weirs and high-lift, gated dams using either tainter or Sidney gates.

The Kanawha River navigation system was initially developed in the period from 1875 to 1898. The navigation system presently has three navigational complexes. One, Winfield, has three lock chambers, while the other two, Marmet and London, each have two lock chambers. With the exception of one of the chambers at Winfield, each lock is 360 feet in length and 56 feet in width. The third chamber at Winfield is 800 feet in length and 110 feet in width. With the exception of the large Winfield chamber, all the present locks on the Kanawha were constructed in the 1930s. The large chamber opened in January 1998. Each Kanawha River complex has a non-navigable, high-lift, gated dam with roller gates.

The Mississippi River has a total of 28 navigational complexes, six of which have dual locks. Locks range in size from 400 feet long and 56 feet wide near Minneapolis to several 1,200 foot long and 110 foot wide chambers further south. The oldest of the present locks, Auxiliary Lock 14, opened in 1922, while the most recently constructed, the auxiliary Melvin Price lock, opened in 1994. All dams are high-lift, non-navigable structures. The older dams employed roller gates, while the more recently constructed dams employ Tainter gates.

Locks

The earliest locks on the river systems of the Ohio Valley were constructed on stone. As concrete technology developed, it replaced stone as the favored lock wall material. Now all the locks of the five systems are constructed of concrete.

Most locks on the five river systems studied use miter gates, the most frequently used lock gates in the United States. Each gate consists of two leaves of equal size. Each leaf is hinged at the top

by means of a gudgeon pin, a fixed part of the leaf, which seats in a gudgeon or eye connected to the wall by adjustable anchorage bars. Directly below the gudgeon pin, on the bottom of the gate leaf, is a socket called the pintle bushing in a heel casting. The gate is suspended in position by the gudgeon and the pintle, the two points about which it pivots when in movement. Modern miter gates are fabricated of structural steel with horizontal, vertical, and diagonal members (Engineer School 1940:57).

Some of the larger miter gates were vertically framed while the smaller and all of the more modern gates are horizontally framed. The older vertically framed gates consisted of a large horizontal top girder and several smaller vertical beams. Load transmitted to the vertical beams was resisted by the top girder at the top and the gate sill at the bottom. The top girders reacted against one another and against the top of the lock walls.

Other gates that have been used or are in use at slackwater navigation systems of the United States include rolling gates and lift gates. As noted, rolling gates were pioneered at Davis Island Lock and Dam on the Ohio River and were later used in many of the numbered locks of the original system.

Lift lock gates resemble the vertical lift gates used at some non-navigable, high-lift dams. The lift gate is opened by either raising or lowering it between two piers or uprights on which vertical supporting tracks are laid. Lift gates were used for some locks on the Mississippi River, as well as locks on some of the western rivers.

While early locks were filled and emptied by use of valves or wickets contained in the gate, most modern locks now use a culvert system with valves to fill and empty the chamber. Culverts used on the rivers have been of two basic types. The more common arrangement has culverts extending lengthwise through the lock walls with side passages to filling and emptying ports in the lock chamber walls. Less frequently used was a design where individual filling and emptying culverts extended laterally through the river wall and allowed each port to fill from or empty to the river. The most common valve type of earlier locks was the butterfly valve, a typically circular valve that pivots on either a horizontal or vertical axis. The most common modern valve type is the Tainter valve. Less commonly found are cylindrical valves and Stoney valves.

All of the Allegheny River locks use miter gates. All are single locks constructed in the 1920s and 1930s. Each of these locks is similar in construction. All have concrete walls with filling and emptying culverts placed within them. Filling and emptying of each lock is controlled by a series of butterfly valves. For example, Lock No. 2 has eight filling ports on each wall, two eight by ten foot butterfly valves placed in each culvert, and one emptying and one filling valve, both eight feet by ten feet. Lock gate machinery is of the "Ohio River type" similar to that used on all the Monongahela River and upper Ohio River locks. The gate machinery is of the standard rack and sector gear type used throughout the Pittsburgh District. Both the lock gates and valves are hydraulically operated.

The earliest locks of the Monongahela River Navigation System were constructed of coursed, tooled stone, the typical material for mid-nineteenth century locks. Beginning with Lock No. 10, started in 1897, locks on the Monongahela River were constructed of concrete. As a result, Lock No. 10 was one of the earliest concrete locks in the Pittsburgh area. Thomas and Watt note in their book, *The Improvement of Rivers*, that the use of concrete for river works was "practically untried" in the United States until 1892, although it had been used for other hydraulic works for many years. The authors cite the Illinois and Mississippi Canal (1894) as one of the earliest uses

of concrete for river work (Thomas and Watt 1913:430, 432). By the twentieth century, concrete had supplanted stone masonry as the building material of locks.

The locks on the Monongahela River use several types of valves, depending largely on date of construction. One lock, the river chamber of Locks and Dam No. 3, still uses cylindrical valves. These valves were installed at the same time in several other lower river locks, but the other locks have either been eliminated or reconstructed. Other older locks, including Locks 2, Locks 4, and Morgantown, use butterfly valves. The most recently constructed locks on the Monongahela use reverse tainter valves. In addition, the river chamber of Locks No. 3 uses compressed-air powered wickets in its gates to supplement the cylindrical valves, while Locks No. 4 also uses compressed-air powered wickets to aid in filling and flushing out the chamber.

With the exception of the land chamber at Locks and Dam 3, all of the locks on the Monongahela River use a longitudinal culvert system for filling and emptying the chamber.[6] Most of the locks use hydraulically operated lock gate mechanisms and valve mechanisms. The oil in the hydraulic system is pumped by hydraulic pumps located in a central control building through a network of pipes to the machinery. The two newest locks, Grays Landing and Point Marion, eliminate the need for a network of hydraulic pipes by using self-contained, packaged hydraulic systems to operate each of the lock gates and valves. The gate machinery itself, which uses a rack and sector gear powered by a hydraulic piston, is standard throughout the Pittsburgh District, except for Grays Landing and Point Marion.

The initial locks on the Kanawha River were constructed using stone masonry lock walls (Johnson 1977:88). A typical early Kanawha lock was Lock and Dam 6, completed in 1886. The lock was 410 1/2 feet long on the outside and 342 feet long and 55 feet wide inside the chamber. Lock gates were constructed of white oak and turned on heavy steel pivots. Five valves were built into the lock gates. The 1930s-era locks of the Kanawha River were of concrete construction and used steel mitering gates. The side filling locks of the Kanawha are provided with 8 by 10 foot main culverts, five by eight fopot intake ports, four by five foot and five by eight foot discharge ports and ten lateral ports (Kemp 2000:255). The London, Marmet and Winfield locks were each constructed with four Stoney gate valves. These valves remain in use (Kemp 2000:103). These locks use a gate jack mechanism including a hydraulic cylinder with the piston rod connected to a rack, which in turn was meshed to a tooth sector wheel (Kemp 2000:255). The operation of this mechanism is described in *Great Kanawha Navigation*, prepared by the West Virginia Institute for the History of Technology:

> The gate jack consisted of a hydraulic cylinder with the piston rod connected to a rack. The rack was meshed to a sector arm of a tooth wheel having an attached arm, with a connecting arm which was attached to the valve. The valves were opened and closed by a single stroke of the piston. The operation machinery was set in a recess in the lock walls, shimmed to grade, aligned and adjusted to the gates and concreted into place (WVU n.d.:109).

The locks and dams constructed on the Mississippi during the 1930s were 110 by 600 feet in size. These locks employed monolithic reinforced concrete walls. The locks of the upper Mississippi constructed in the 1930s used tainter valves. The valves were raised and lowered from above by

[6] The 56 foot by 720 foot land lock at Locks and Dam 3, Monongahela River, fills through the wall. The filling valves fill from a covered flume or flumeway which draws water from the upper pool. This filling system is a transitional hybrid between the round valve culverts perpendicular to the lock wall and the modern longitudinal culvert system.

electrically driven cable hoists. Seals on the sides and bottom of the valves enabled them to close off the culverts in the lower position (O'Bannon 1989:54). Vertically-framed miter gates, pivoting on steel pintles and supported, when closed, upon steel beams embedded in the reinforced concrete gate sills, also operated electrically (O'Bannon 1989:26, 53; O'Brien et al. 1992:87).

Lock No. 27 of the Mississippi, whose construction began in 1947, employed double-leaf, vertical lift gates for the upper gates. With the lock emptied and the lower miter gates fully opened, the downstream leaf of the lift gate may be lowered until it nests behind the upstream leaf. Ice may then pass freely through the lock chamber. The lift gates are raised and lowered by electrically operated, counterweighted chain hoists (O'Bannon 1989:59).

In the upper Mississippi locks, the small culverts used on the Ohio were replaced by large longitudinal culverts located in the base of the lock walls controlled by only four valves. Intake and discharge openings were located in the lock walls, respectively above the upper gates and below the lower gates. A series of small ports branched off the main culverts and flooded or emptied the lock chamber (O'Bannon 1989:53). In post-World War II locks, the intake ports for the filling culverts are located in the floor immediately above the upper gates. For discharge, a complex discharge manifold was installed that releases water through the floor of the lock below the lower gates. This discharge system was designed to reduce turbulence (O'Brien et al. 1992:128).

Among the most notable elements of the early Ohio River locks and dams was the introduction of the rolling lock gate used to span the unprecedented 110 foot width of the Davis Island Lock chamber. Rolling gates were used until miter gates capable of spanning a 110 foot wide opening were developed. The first of these wider miter gates were installed at Emsworth Lock in 1922 and represented a pioneering use of gates of this width.

The Ohio River rolling lock gates were supported on ten sets of axles with fixed wheels that ran on a plate and channel track embedded in the concrete lock gate sill. Each axle was about 13 feet long and eight inches square and weighed about 2,100 pounds. On each end was a cast steel flanged wheel of 33-inch tread diameter and 7-inch tread width. The wheels and axles suffered corrosion due to pollution of the Ohio near Pittsburgh, and in the 1950s, the wheel and axle units of locks 7 to 13 were replaced (Combs 1954:440-441).

The numbered locks on the Ohio River were also the site of the first use of steel wall armor to protect concrete lock walls from the impact of vessels. This wall armor is now a standard feature in most United States navigation locks. While wall armor used on other locks such as those on the St. Lawrence Seaway is vertical, that used on the Ohio River is horizontal.

The Ohio River navigation system is also notable in showing the evolution of lock filling and emptying technology. Early locks were filled and emptied by valves in the gates and by valves and culverts in the river wall. In general, 17 individual filling and 17 individual emptying culverts brought water from the river and discharged water to the river. Synchronization of valve opening and closing was provided by hydraulic jacks. In the next generation of locks, the individual culverts were replaced with larger longitudinal culverts in each lock wall. These culverts, variously controlled by Stoney, butterfly, tainter or reverse tainter valves, permitted a more rapid filling and emptying of the lock chamber. Intake and outflow of water was through ports in the lock walls. To reduce turbulence in the lock chamber, more recently constructed locks have

incorporated deflection ports and culverts underneath the lock floor that discharge directly into the river.

Dams

Dams are critical elements of slackwater navigation systems. By allowing water to pool behind them, these dams provide the depth of water needed for safe navigation of the river. The earliest dams on slackwater navigation systems had fixed crests and were generally of timber crib construction filled with stones. Such construction was used in nineteenth century dams on the [Kanawha,] Allegheny and Monongahela rivers. These wood crib dams were prone to damage and failure due to flooding, debris, and ice floes. In several instances on the Monongahela, large sections of these dams washed away, and in other cases the crests were severely damaged. The dams also tended to leak badly and underseepage posed problems. As concrete technology improved, newer dams were constructed of this more durable material. Existing timber crib dams were sometimes capped or partially reconstructed in concrete.

Fix crest dams had their disadvantages. During dry periods, the insufficient amount of pooled water sometimes required suspension of lock operation. Because of the inability to change crest height, these structures are not navigable. In addition, in a complex with a fixed crest dam, high flood levels can cause cessation of lock operations more frequently than in one with a gated dam.

As noted, the first distinct type of movable dam was the beartrap, erected in 1818 on the Lehigh River of eastern Pennsylvania. It consisted of two wooden gates revolving on horizontal axes at the floor level. The downstream gate points upstream, and the upstream one pointed downstream, the latter resting on the edge of the downstream gate when raised. The dam was operated by water running under the gates through culverts and forcing them up (Thomas and Watt 1913:II:538).

The needle dam, the first movable navigational dam, was developed in France by M. Poirée in 1834 (Thomas and Watt 1913:538). An improved movable dam was invented in 1852 by Jacques Chanoine, Chief Engineer of the French Corps, and first used on the Seine River near Paris. The Chanoine dam consisted of a masonry foundation to which boards, called wickets, were hinged. When the wickets were down, boats passed over them in a navigable pass. When the river level dropped, threatening navigation, the wickets were manually pulled up. The channel was closed and water was backed up forming a slackwater pool. With the river level low, boats navigated slackwater pools and were moved from pool to pool by locks. When the river rose, the wickets were dropped, and the channel was again opened to traffic (Johnson 1977:84).

Colonel William E. Merrill pioneered the use of movable dams on American rivers. In 1874, he proposed to use Chanoine wicket dams on the Ohio River navigation (Johnson 1985:40). A colleague, Godfrey Weitzel, who collaborated with Merrill on movable dam studies, used several European systems later in the century on the Louisville and Portland Canal and the Sault Ste. Marie Canal (Johnson 1985:133).

Movable crest dams were introduced to the Ohio River area on the Ohio and Kanawha rivers. Among the early types of movable crests were Chanoine wickets, Bebout wickets, Boulé dams, and beartraps. The Bebout wicket is similar to the Chanoine wicket except that it is designed for automatic tripping. The Boulé dam consists of a series of collapsible trestles which support movable shutters. To install the dam, a maneuver and a shutter boat was needed. The remainder of these types of movable crest dams, developed in Europe, were first used in the United States

on either the Kanawha or Ohio River systems. Only the beartrap was used on the Monongahela River and that in lock chambers, not on the dam.

The Great Kanawha River Navigation was the second lock and dam system of the Ohio River area to employ movable dams. These dams, erected in the last quarter of the nineteenth century, were composed of a long line of wickets, each 3 feet 8 inches wide and hinged on the bottom that could be dropped to allow navigation over them in high water or raised to pool water during dry periods.

Leland Johnson, in his history of the Huntington Corps of Engineers District, described Dam 6, a typical dam of the Great Kanawha navigation:

The masonry foundation of the dam was 568 1/2 feet long and 50 feet wide. The navigation pass through which river traffic passed at high water was closed with 62 Chanoine wickets, each 3 feet and 8 inches wide and 13 and 5 1/2 inches long. The weir, which regulated the depth of the slackwater pool, was 310 1/2 feet long, closed by 69 Chanoine wickets smaller than those in the navigable pass. A metal service bridge, on which men stood when moving the wickets, extended across the dam above the wickets; the bridge also could be collapsed on the dam foundation at high-water stages (Johnson 1977:89).

This same type of dam was also used at Davis Island on the Ohio River.

The Monongahela River made early use of automatic movable crest dams. Neither of the two types used on the river, the Chittenden drum or the Betwa wicket, proved successful from a maintenance and durability standpoint. Where these devices proved unworkable, they were replaced, and the dams were permanently raised with a concrete top.

The present dams on the Monongahela River are a mixture of fixed concrete weirs and gated structures. One of the concrete weirs, Dam 3, is particularly interesting because of the survival of its middle pier. According to a lock employee, this pier is expected to contain remaining machinery from the Chittenden drum operating mechanism installed in the dam at the time of its original construction. The other two remaining fixed concrete weirs range in date of construction from 1905 (Lock No. 2) to 1996 (Grays Landing Lock and Dam).

During the twentieth century, modern, high-lift, adjustable crest dams were developed. These types, each of which is still in use include the roller gate, the tainter gate, the Sidney gate, and the vertical lift gate. As mentioned, use of the roller gate was pioneered on the Kanawha River, and these gates are now used on the upper Mississippi River and at Gallipolis Dam on the Ohio (Engineer School 1940:35).

The tainter gate is an internally framed sector of a cylinder with a system of radial bracing (end frames) at each end which carries the gate load to a trunnion pin. The trunnion pin is anchored to the pier, and the arm and gate rotate about this pin (Engineer School 1940:35). Tainter gates were pioneered on the Mississippi River and are presently used at all the Monongahela River movable crest dams and at movable crest dams on the Ohio. In the 1930s, electrically driven chain-hoist machinery was introduced on the upper Mississippi replacing the earlier gates lifted by a service bridge-mounted crane. This improvement allowed the simultaneous raising of all the gates, when necessary (Kemp 2000:104).

The Sidney gate is a special type of tainter gate with movable or sliding trunnion pins. The gate was designed to overcome the disadvantage of limited maximum clearance of other Tainter types (Engineer School 1940:42). A Sidney gate is used in the back channel section of the Emsworth Dam on the Ohio River, as well as at Dam No. 4 and Point Marion Dam on the Monongahela River.

The vertical lift gate is framed with trusses or built up girders which support the watertight skin plate or sheathing. The gate contacts the sides of the piers with fixed rollers that move in vertical recesses in the piers (Engineer School 1940:44). The vertical lift gate is used at the Emsworth and Montgomery Island dams on the Ohio. The Emsworth lift gates could be lowered some three feet below upper pool and could function as overflow gates.

All of the extant dams on the Allegheny River are fixed crest concrete weirs. The earliest of these dams, constructed in 1927 and 1928, are of concrete construction resting on a stone-filled wooden crib and wood bearing pile foundation with a steel sheet pile cut-off wall on the upper side of the dam and a 20 foot wide stone-filled crib on the lower side (Dravo 1947:26).

The replacement dams on the Great Kanawha navigation use non-navigable roller gate dams. The roller gate dams on the Kanawha were among the first in the United States. Dravo Corporation held American rights to the gates and the gate hoists of the roller-gate dam and was awarded the contract for construction of roller gate dams at Marmet and London (Johnson 1977:137) in 1932 (Miller 1950:58). The London and Marmet dams consist of five roller gates, each 100 ft. 3 ½ inches in length between piers and 26 feet in diameter. Four are standard roller gates, while the fifth has a flap to allow for ice and debris discharge (Kemp 2000:253). The Winfield Dam employs six roller gates including one with a retractable flap (Kemp 2000:257).

Roller gate dams were subsequently constructed elsewhere on the Kanawha and on the Ohio. In 1937, the Winfield Locks and Dam on the Kanawha was completed, and the following year, the Gallipolis Locks and Dam on the Ohio was finished (Johnson 1977:139). As of March 1939, a total of 146 roller gates had been installed in dams in the United. The longest of these gates were the 125 ½ foot gates at the Gallipolis Dam. The major proportion of these gates had been installed on the Mississippi River. In addition to Ohio and Kanawha river gates, these gates were used on reservoir and irrigation dams including installations in Colorado, Pennsylvania,[7] Idaho, Massachusetts, California, Washington and Maine (Martin 1939:67).

As mentioned, the early Ohio River dams introduced the movable dam to the United States, using dams and weirs of Chanoine wickets (Johnson 1977:92). These early dams were also notable for the use of beartrap gates, initially installed to pass drift without lowering wickets, and later used for passing minor rises and maintain pool levels without lowering wickets (Johnson 1977:95). Most of these beartraps were of the two-leaf type except at Dam No. 13, where two gates of the Reverse Parker three-leaf type were installed (Altstaetter 1914:504).

Beginning in the 1920s, a series of higher lift dams were constructed on the Ohio River to replace the earlier wicket dams. The oldest extant dam on the Ohio, Dashields, dates from this period. Dashields has the only remaining fixed crest concrete dam in the Ohio River navigation system.

During the 1930s, the first in a new generation of movable crest dams were constructed on the Ohio River. The Emsworth Dam, constructed in 1935 through 1938, replaced an earlier fixed

[7] The Pennsylvania installation was at Lake Wallenpaupack, a reservoir in the Poconos

crest concrete dam. The Montgomery Dam, constructed between 1932 and 1936 eliminated the original Ohio River Dams 4, 5 and 6. Both of these dams use vertical lift gates. In 1940, other vertical lift gates were used at the Bonneville Dam on the Columbia River; at Dam No. 17, Warrior River; and at the Savannah Bluff Dam (Engineer School 1940:I:45). More recently constructed Ohio River dams, including New Cumberland, Pike Island, and Hannibal, use Tainter gates to vary the dam crest height with New Cumberland and Pike Island using both non-overflow and submergible tainter gates, and Hannibal only non-overflow tainter gates.

The hydrological characteristics of the upper Mississippi River and the Ohio River are different, precluding the use of a first generation of dams modeled after the navigable wicket dams already in use on the Ohio (O'Bannon 1989:26). In their study of the Mississippi River Nine-Foot Channel, the authors of *Gateways to Commerce* contrast the Ohio River and the Mississippi:

> The Ohio River experienced extended periods of high water that permitted long periods of open river navigation, but necessitated dams capable of passing large amounts of water. Wicket dams, such as the Chanoine wicket dam constructed at the Davis Island site on the Ohio River, accomplished both of these ends....
>
> The non-navigable dams of the Upper Mississippi offered several advantages over the navigable wicket dams on the Ohio. Wickets had to be either fully raised or fully lowered. But the Corps could set the gates on the Upper Mississippi dams to any desired opening, permitting accurate regulation of pool heights. The high sills of non-navigable dams also ensured a minimum pool level, an advantage in a shallow river such as the Upper Mississippi (O'Brien et al. 1992:41).

Dams of the upper Mississippi nine-foot channel project were of the movable, non-navigable type. These non-navigable dams consisted of a series of reinforced concrete piers, supported on concrete foundations, with movable gates that close the openings between the piers (O'Bannon 1989:30). The earliest constructed dams of the upper Mississippi nine-foot channel employed roller gates, while a majority of the dams constructed on the upper Mississippi used tainter gates (O'Bannon 1989:39). Initially, because of limitations on tainter gate size, the main channel at each dam used roller gates, while the other portions used smaller, simpler Tainter gates (O'Bannon 1989:41). As construction of the nine-foot channel progressed, tainter gate design was refined, and wider and more efficient gates were practicable (O'Bannon 1989:45-46). By the end of the 1930s, 80-foot submergible gates had been perfected (O'Bannon 1989:47). Beginning with the construction of Lock and Dam 24, only tainter gates were used on the river (Kemp 2000:104).

An important area of engineering significance for the Ohio River is the evolution of dam technology. As noted, at Davis Island and the subsequent numbered locks, a navigable pass and movable and fixed weirs were employed. Much of the technology was imported from Europe, while the beartraps used represented the improvement of technology developed in early nineteenth century Pennsylvania. When completed, the original Ohio River Navigation System represented the most extensive complex of navigable pass dams in the United States.

As replacement of the navigable pass dams occurred, and non-navigable, high-lift dams were constructed, the Ohio River continued to be in the forefront of dam technology. Among the significant Ohio River landmarks were the construction of the largest roller gates in the United States at Gallipolis Dam, and the first use of a Sidney gate in the back channel dam at Emsworth.

The Ohio River engineers also contributed to tainter gate technology by the installation of wide-width gates and the development of submergible and non-submergible tainter gates.

Power Systems

The oldest locks of the Ohio River Valley were operated by hand. For instance, the earliest lock gates of the Monongahela River Navigation were opened and closed by chains attached to hand-powered capstans. By the 1870s, however, mechanized lock operation had begun to be developed in the Ohio River area. In 1876, Superintendent George W. Lutes of the Monongahela Navigation Company installed a waterwheel to take advantage of the current that passed over the dam at Lock 3. The power generated operated a series of drums, shafting, clutches and gearing and allowed the mechanized opening of a lock gate in 30 seconds. Soon after, this system was installed in Locks and Dams 1 through 4.

Steam engines were later used to provide power for the lower river locks on the Monongahela. For instance, at Monongahela River Locks No. 1, the gates were operated by steam power, excepting in the river wall of the river chamber where power was derived from a waterwheel placed in the dam. The machinery for the lock gates on the shore and middle walls was worked by steam power. A steam engine was located on each wall. The steam for the engine on the middle wall was carried from boilers on shore by an overhead steam pipe supported by an iron framework.

In the early twentieth century, compressed air became the motive power of all new or reconstructed Monongahela River locks. For example, in Locks and Dam No. 5, a water turbine was connected by bevel gears to an air compressor. Air, at 100 pounds pressure, was piped from the reservoirs to all the engines operating the valves and gates. One stroke of the cylinder opened or closed one of the miter gates in 40 seconds.

Davis Island Lock and Dam, the earliest navigational complex on the Ohio River, employed a turbine to operate lock machinery with a steam engine used as backup. Other early Ohio River locks used either steam or turbine power or a combination of both.

The Deadman Island Locks and Dam (now Dashields) on the Ohio River, constructed beginning in 1927, had gate and valve operation powered by hydraulic turbines, using oil pressure transmitted through oil lines to the gate- and valve-operating machinery. An electrical generator, also turbine driven, furnished current for light and power (Casey 1929:444).

Control valves were provided on the three walls of the Deadman Island locks for several combinations of operations. The controls for the valves were located at the middle of each lock wall. The controls for the large lock gate were located just downstream and upstream respectively from the upper and lower gate recesses, while those for the small lock gate were located at the gate recesses (Casey 1929:446).

Turbine power has been eliminated at all locks and dams on the Ohio River. All presently use electric power from the outside power grid to run hydraulic pumps. These hydraulic pumps, in turn, operate the lock gates and valves. This system is similar to that used on the Monongahela River.

Post-World War II locks on the Monongahela River, beginning with the Morgantown Lock and Dam, were constructed using oil-fed, hydraulic power to operate the gates and valves. Older locks

retained the compressed air system until renovations occurred. For example, Locks and Dam No. 3 were converted from compressed air to oil-fed hydraulic operation in 1978.

The first generation of Allegheny River Lock and Dam complexes were completed in the first years of the twentieth century. Initially, the Herr Island Lock and Dam (No. 1), the first to be completed, was to be operated hydraulically, using a turbine to supply power. To cut down on cost, it and the other first generation Allegheny River locks used hand-powered capstans to operate the lock and its wickets (USACE-ChE 1902:1905).

Locks and dams on the Allegheny River presently use two types of power generation. The older power system uses from one to three hydraulic turbines to power the hydraulic system operating the lock gates and valves. The original turbine system at Lock and Dam 4 has been replaced with an electrical system similar to that used presently at all the locks and dams on the Monongahela. The system at Lock and Dam 5 is scheduled to be replaced in the near future. This system is significant as among the oldest operating turbine power system in the Ohio valley area.

The first generation of Kanawha River locks, constructed in the final decade of the nineteenth century, were also hand powered using capstans and wickets. The second generation of locks on the Kanawha, constructed in the 1930s, used hydraulically operated gates and valves.

The locks of the Mississippi River Nine-Foot Channel Project, constructed in the 1930s, used electrically operated locks and valves. The gates, as typical of modern locks, were opened and closed by means of steel sector gears and struts, while the mechanisms of the tainter valves were cable-driven (O'Bannon 1989).

The upper Mississippi Lock No. 27, constructed between 1947 and 1953, incorporated departures from earlier construction practice. Six separate control stations replaced the single central control station used at earlier installations. These control stations were located at both ends of the east and intermediate lock walls, the upper end of the west wall, and the mid-point of the intermediate wall. Bulkheads, placed by stiffleg derricks, are provided to close off the upper gate bays of the locks for repairs. Unwatering pumps, located within the lock walls, are then used to completely empty the lock chambers (O'Bannon 1989:59). Mississippi River locks are also powered by electric-hydraulic systems.

The authors of *Canalization* cite factors affecting the decision to use either electrical or hydraulic machinery:

> Perhaps the chief factor influencing the choice of type is the likelihood of submergence of the machinery. If the lock walls are to be periodically overflowed, electrical machinery will have to be removed and replaced several times a year in order to avoid danger thereto, whereas hydraulically actuated machinery is not affected by completed submersion. This last consideration accounts for the fact that hydraulic lock operating machinery is standard on the Ohio, whereas electrical operation is standard on the Upper Mississippi (Engineer School 1940:389).

The Ohio River Navigation System is significant for its role in the evolution of power generation in navigational complexes in the United States. As noted, the earliest locks and dams on the river used either a steam engine or turbine system for power generation. Initially, machinery was operated by either steam or compressed air. With the extension of the power grid, the complexes

began to use electrical power for operation. Because of the potential for flooding, direct electric operation of lock machinery was not employed. Instead, electricity is used to power a hydraulic system that operates both gate machinery and lock valves.

Emergency and Maintenance Closure

Except when a lock is filling or emptying, when both gates are closed, one gate of a lock is generally closed and withstanding full hydrostatic head, while the other gate is open. Should the closed gate fail, the river would at once flow through the lock. Such failure of a gate has occurred either through structural defects or as the result of one gate being rammed before the other gate could be closed behind the entering vessel. The effect of such a failure and its consequent rush of water can be disastrous to the lock and nearby vessels. To prevent this from occurring, methods of closing the lock and stopping the rush of water have been devised. These same devices, if installed both above and below the chamber, may also be used for periodic unwatering of the chamber and gates for maintenance and repair (Engineer School 1940:65-66).

Emergency and maintenance closure devices have included the Poirée dam, the needle dam, a massive gate of structural steel, constructed to span the forebay from wall to wall, and double lock gates. The Poirée dam is used exclusively for maintenance closure. The sills, trestles or trestle boxes and anchorages for the Poirée dam are installed during lock construction. To close the lock, the trestles, if the hinged type, are raised; if the box type, are installed by a diver. The crosspieces and needles, stored at the site, are then placed by crane. When needle dams are used, the supporting frames may be installed during construction and left collapsed on the foundation until needed, or they may be made portable and moved from site to site where they are fitted to a specially prepared sill. Emergency needle dams are ordinarily used only on the downstream side of the installation to be unwatered where the head is relatively low. Steel or aluminum bulkheads are used above the dam to support the upper pool head. The structural steel gate is stored on a bank beside the lock and can be swung out and lowered into position by a crane. Double lock gates are less common but were installed at St. Marys Falls and on the Welland Canal (Engineer School 1940:22, 66).

The earliest locks on the Monongahela River Navigation System used beartraps for maintenance closure. When the upper beartrap leaf was raised to a level with the surface of the upper pool, the miter gates could be thrown open and fastened back.

At Monongahela locks No. 2, Boulé dams are used for maintenance closure (Rockovich 1999). A Boulé dam is permanently installed in the bottom of the chamber and consists of a number of collapsible trestle which support movable shutters. Each trestle is a structural steel A-frame placed at right angles to the dam. Needle dams are used for maintenance closure at Locks 3 and 4 of the Monongahela. The present Poirée dams consist of removable A-frame trestles, standard to the Pittsburgh District. Poirée dams are used for maintenance closure of the lower ends of the chambers at Morgantown, Hildebrand, and Opekiska. The newer Monongahela River locks, and those recently rehabilitated, each have a bulkhead system to close off the lock chamber. In most of the complexes, separate bulkheads are used for the lock and the dam, while the width of the Opekiska and Maxwell dam gate bays was designed to allow the use of the same bulkheads for both lock and dam, The Lock 2 (56 foot chamber) overhead "garage door" emergency bulkhead system is believed to be innovative and is found only at that lock and at Grays Landing on the Monongahela River.

Emergency and maintenance closure of Ohio River and Mississippi locks is provided by

bulkheads similar to those used on the Monongahela, except for Emsworth, Dashields, Montgomery, and New Cumberland. These first three complexes use Boulé dams similar to those used at Monongahela River Locks No. 2 for maintenance closure. The latter uses Poirée dams in the downstream end. The Allegheny River locks lack emergency closure systems and most use needle dams for maintenance closure (Rockovich 1999).[8]

The tainter gate Dam No. 4 has an emergency closure system typical of the Monongahela River. It is equipped with two steel bulkhead sections that are dogged between piers. The bulkheads ride in slots on the sides of the piers and are placed by the lifting beam of the traveling bulkhead hoist on the service bridge. Opekiska and Maxwell are designed to use the same bulkheads for lock and dam.

The Ohio River movable dams use an emergency closure system similar to that of the Monongahela. For example, the lifting beam used at Opekiska is similar to that used at the New Cumberland Locks and Dam on the Ohio. Upper Mississippi River dams constructed in the 1930s used temporary blocking units of structural steel girder construction to block gate openings during periods of emergency or repair of the Tainter gates. These emergency bulkheads were stored on land and were moved into place by locomotive cranes located atop the service bridge.

Closure above the Upper Mississippi and Kanawha River roller gate dams was accomplished by lowering a series of specially designed girders called "stop logs" that bear in slots in the piers. The girders were handled and placed by a traveling hoist. The downstream closure was accomplished by a series of Poirée trestles and needles (McAlpine 1934:423).

The use of Poirée dams, Boulé dams and bulkheads for maintenance and emergency closure of locks and dams is common in the Ohio River, Mississippi River, and Monongahela River systems. Therefore, the use of these methods of closure does not appear to add to the engineering significance of the Ohio River Navigation System.

Construction Methods

As noted, early United States river locks were constructed from mortared stone. This technology was used in the original locks on the Monongahela, Lock No.1 (Davis Island Lock) on the Ohio, and the original Kanawha River locks. According to the 1894 *Annual Report of the Chief of Engineers*, the first locks in the United States believed to have been constructed entirely of concrete were begun in 1892 and 1893 on the Illinois and Mississippi Canal. These locks were designed by Captain William L. Marshall of the Corps of Engineers (as cited in Black 1929:206). All of the present locks on the Ohio, Mississippi, Monongahela, and Allegheny rivers are of concrete construction.

Among the main technological innovations in lock and dam construction methods in these slackwater systems were in cofferdam construction. The earliest cofferdams used in lock and dam construction in the United States consisted of a dike of earth. Later, these dams were made more watertight by the installation of a central cutoff wall of wood sheeting and the covering of the dike with riprap to prevent scour. These dams suffered severe damage during periods of high water (Jansen 1948:26).

[8] Lock and Dam 2 on the Allegheny River has no permanent provision for maintenance closure on the downstream side. Closure is accomplished by a construction of sheetpile box cofferdam.

In the early twentieth century, the Ohio River-type box cofferdam was developed during the construction of navigational structures on that river. This type of cofferdam consisted of two rows of wood sheeting spaced 16 feet to 20 feet apart, with timber wales on the outside, held together with steel rods passing through the wales and sheeting (Jansen 1948:27). This cofferdam required two kinds of plants on each job, a floating plant for use on the outside of the cofferdam and for building the cofferdam itself, and a land plant for work inside the cofferdam. This cofferdam was low in height and occasionally suffered heavy damage from high water (Jansen 1948:28).

To address the perceived disadvantages of the Ohio River-type box cofferdam, the internally braced, interlocking steel sheet pile cofferdam was developed and was first successfully used at Dam No. 23 on the Ohio River in 1928-1929.[9] This type of cofferdam permitted the use of floating equipment almost exclusively. Further development of the interlocking steel sheet pile cellular cofferdam occurred in the construction of the Dashields Dam on the Ohio River in 1928-1929. This fixed dam was constructed in five sections of cofferdam, using cells 40 feet in diameter spaced 42 feet from center to center. This type of circular cell cofferdam permitted continued work in flooded conditions (Jansen 1948:28-29).

The most recently constructed locks and dams, such as Grays Landing on the Monongahela River and the recently constructed Ohio River complexes continue to use circular cell, sheet pile cofferdams in construction. In some cases, such as the reconstruction of Locks No. 2 on the Monongahela River, a diaphragm type, cellular cofferdam was used to mount cranes and other construction machinery (Larkin 1950:35).

The first generation of Allegheny River locks and dams were built in the early twentieth century. The lock walls and dam were constructed within Ohio River box cofferdams (Dravo 1947:8). The second generation of locks and dams were constructed beginning in the late 1920s. For example, Allegheny Dam No. 5 (Miller 1950:56) and Lock No. 7 was constructed within a double wall steel pile type box cofferdam that consisted of two rows of piling 20 feet apart, held together by steel rods and filled with sand and gravel. The plant for Lock No. 7, operated by Dravo Corporation, included a 2-yard land mixer to which cement was fed by a belt conveyor (Dravo 1947:31). Allegheny River dams 5 and 6 marked the first use by Dravo Corporation of steel piles in a box type cofferdam. The tie rods used to hold together the steel piling were spaced about ten feet apart longitudinally and about three feet vertically. Floating equipment used in construction included Dravo whirler boats and mixing boats (Dravo 1947:26). Lock No. 6, atypically for Allegheny River locks, used a cofferdam formed from a single line of sheet piling, bermed on both sides. Contractor for this project was the John F. Casey Company (Miller 1950:56).

The oldest of the present Ohio River locks and dams, Emsworth, was constructed by Dravo Corporation in the early 1920s. The lock was constructed within three sections of Ohio River box cofferdam de-watered by a motor-driven pump boat. Other equipment used in lock construction included a steam shovel, drag line excavator, and whirler cranes. A movable mixer was used for placing concrete in the land wall and middle wall, while the river wall used a floating mixer plant. Concrete was transported to the walls from outside of the cofferdam by chutes (Dravo 1947:22).

As mentioned, the original Dashields dam on the Ohio River, a concrete, fixed crest structure, was erected by Dravo Corporation in 1928-1929 within a circular cell type cofferdam. The Dravo

[9] Other early uses of this cofferdam type included Black Rock Lock on the Niagara River, Browns Landing Lock on the Cape Fear River in North Carolina, and the Forty-Sixth Street Pier in New York City (Black 1929:206).

engineers found this new type of cofferdam exceptionally water-tight and quite superior to the Ohio River Type box cofferdam (Dravo 1947:29-30). This dam is still in service today as a fixed crest dam.

The Gallipolis Locks and Dam on the Ohio were constructed by Dravo Corporation in the 1930s. A cellular steel sheet pile cofferdam was constructed to enclose the entire 2,158 feet of lock, using two lines of sheeting, connected with cross walls at 35 foot intervals. The cofferdam was filled with sand and gravel and the whole was capped with concrete (Dravo 1947:43). The type of cofferdam used is generally termed a diaphragm type, cellular cofferdam.

More recent projects on the Ohio have continued to modify existing cofferdam types to suit the particular construction situation. For example, at Newburgh Locks and Dam, cofferdams were constructed inside a main cofferdam to allow for deeper excavation for founding of piers. After the failure of cofferdams at Canneltown and Uniontown locks, the Stage I cofferdam for Hannibal Dam was redesigned with the incorporation of prestressed cable anchors and concrete thrust blocks.

The three extant Kanawha River navigation structures date to early 1930s modernization of that navigation system. The dam cofferdams for the Marmet, West Virginia, Lock and Dam complex were constructed in two consecutive units and were of the cellular type, consisting of a series of circular cells connected on both sides by short arcs, all filled with sand and gravel and paved with concrete. Dravo whirlers were used for excavation and for handling forms, concrete and steel. The floating plant consisted of a mixer boat, derrick boat, and barges (Dravo 1947:36).

The London twin locks and dam used cellular steel, sheet pile cofferdams similar to those used at Marmet dam. The construction plant used Dravo whirlers, a double 2-yard mixing plant, a 2-yard mixer boat, and derrick boat (Dravo 1947:38). The Winfield twin locks were constructed within a box cofferdam, consisting of two rows of arch web steel sheet piling, tied with cross roads and filled with sand and gravel. The dam cofferdam was of cellular steel sheet pile construction similar to that used at the Marmet and London dams (Dravo 1947:40-41).

Mississippi River Locks and Dam No. 26, constructed in the 1930s used a cofferdam constructed of cloverleaf steel sheet pile cells filled with dredged material. This cofferdam represented a modification of the circular, sheet pile cofferdam developed on the Ohio River. Y-connection piles, connected to two structural frames, tied the individual cells together at the panel points (O'Bannon 1989:74). Concrete was mixed on shore and was placed using a network of belt conveyors (O'Bannon 1989:78).

The Ohio River Navigation System is significant for its role in the evolution of cofferdam technology. As mentioned, the Ohio River box cofferdam was developed for use in construction projects on the river. Later, Dravo Corporation made the first successful use of a cellular steel cell cofferdam in lock and dam construction at Dashields Dam. Innovation continues as evidenced by the use of interior cofferdams at Newburgh Locks and Dam.

As mentioned previously, other construction techniques were also introduced on the Ohio River. The Louisville District engineering staff developed pile supported concrete foundations for locks and dams on the sandy bottom of the lower Ohio River. The contractors for Montgomery locks had previously made extensive use of long-span cableways to deliver material to the construction site, an early use of that technology.

RECOMMENDATIONS

The Ohio River Navigation System is recommended eligible for the National Register of Historic Places under Criterion C for significance in engineering. Criterion C states that "properties may be eligible for the National Register if they embody the distinctive characteristics of a type, period or method of construction."

The present Ohio River Navigation System is eligible both for its individually notable engineering features and as a complex that shows the evolution of lock and dam technology from the 1920s to the present. It possesses significance at the national level. Several specific areas of significance are applicable.

- Development of Dam Technology

From the earliest numbered locks to the presently on-going construction at the Olmsted complex, the Ohio River Navigation system has pioneered important developments in dam technology. Davis Island Dam was the first navigation dam in the United States to incorporate a navigable pass, a technology that had been developed in France. The Gallipolis Dam was one of the early uses of roller gates in high-lift, non-navigable dams and has the longest roller gates in the United States. The Sidney gate, a combination of a vertical lift and tainter gate, was first used in the back channel dam at Emsworth and remains in use in that structure. Early tainter gates on the Ohio River were among the largest used at the time of installation. The present dams 52 and 53 with their Chanoine wicket navigable pass represent a survival of an earlier technology, now almost superceded on the Ohio River and elsewhere in the United States. The present Olmsted dam will include a modern, improved version of the navigable pass, the only such structure built on a major American waterway in recent years.

The present dams and the remains of earlier locks and dams possess significance as tangible examples of changing dam technology. In its variety of dam types and dam technology, the Ohio River Navigation System is unmatched among waterways of the United States.

- Development of Lock Technology

The existing locks in the Ohio River Navigation System exemplify the evolution of lock technology. Early structures, such as Emsworth and Locks 52 and 53, employ through the wall filling and emptying with separate culverts for each individual filling and emptying valve. Later locks show the evolution of lock technology with the use of longitudinal culverts controlled by a smaller number of larger valves. The most recently constructed locks show the results of laboratory testing. Discharge systems are used to prevent turbulence in the lock chamber and scour of the lock walls.

The existing locks also demonstrate the use of steel wall armor in the interior of the lock chambers. This armor, now used on most navigation locks in the United States, was first introduced in the numbered locks on the Ohio River.

The variety of construction periods represented by Ohio River locks is matched by the variety of lock valves. The most recently constructed locks use tainter valves in a reverse configuration. Older locks use standard tainter valves, butterfly valves, or in the case of the inactive McAlpine chamber, Stoney valves. The presence of the variety of valves and filling systems provides

significance in lock technology. The Ohio River system is also significant for its role in the development of valve operating machinery. Several complexes on the Ohio were sites of early successful use of wire rope operating machinery for reverse tainter valves.

The locks of the Ohio River Navigation System demonstrate changes in twentieth century lock, culvert and valve technology. Only a few other navigation systems of the United States, notably the Monongahela River, clearly illustrate this technological evolution. The Ohio River Navigation System achieves national significance for its lock technology.

- Construction Technology

The significant role of the Ohio River Navigation System in the evolution of cofferdams is clear. As mentioned, the Ohio River box cofferdam was developed for use on the river. After the effort to recover the *Maine* from Havana Harbor showed the potential of the cellular steel cofferdam, the cofferdam was successfully used at Dashields Locks and Dam. Subsequent projects illustrate the continued evolution of cofferdam and caisson technology on the Ohio River. As mentioned, the construction of the Newburgh Locks and Dams included the use of sub-cofferdams within a main cofferdam to permit safe excavation for piers in the sandy river bottom.

Other potential aspects of significance in construction technology include the first use in American lock and dam construction of long-span cableways to move construction materials to the project site and the development of timber pile construction techniques to firmly anchor locks and dams in the sandy bottom of the lower Ohio River.

The Ohio River Navigation System played a critical role in the twentieth century development of lock and dam construction technology. Technology pioneered on Ohio River projects later became the norm for lock and dam construction elsewhere. Its role in the development of construction technology also gives the navigation system national significance.

- Emergency and Maintenance Closure

Because of the varying ages of the Ohio River's locks and dams, the system illustrates the evolution of closure technology from the emergency closure Boulé dam and maintenance closure Poirée dam to modern lock and dam bulkheads. Although other rivers, including the Monongahela, show a similar evolution of closure technology in their present locks and dams, the variety of existing closure systems on the Ohio River Navigation System contributes to its engineering significance.

To summarize, the Ohio River Navigation System achieves significance as a living laboratory of twentieth century lock and dam technology. It clearly meets National Register Criterion C for its significance in the area of engineering.

ESSAY ON SOURCES

In the course of writing the historic engineering evaluation for the Ohio River Main Stem Study, research was conducted at most of the major archival collections with primary and secondary source material on the Ohio River Navigation System. Collections visited included the Pittsburgh, Huntington, and Louisville district offices of the U.S. Army Corps of Engineers; the Still Photographs and Cartographic and Architectural branches of the National Archives in College Park, Maryland; the Mid-Atlantic Regional Branch of the National Archives (Philadelphia); the Library of Congress; the University of Louisville Library; the Filson Club in Louisville; the Marshall University libraries in Huntington, West Virginia; the Historical Society of Western Pennsylvania; the Carnegie-Mellon University libraries; the Carnegie Library of Pittsburgh; the University of Pittsburgh Library; the Free Library of Philadelphia; the University of Pennsylvania libraries; the Office of History, U.S. Army Corps of Engineers; and the U.S. Army Corps of Engineers Library. In addition to reviewing construction and inspection reports and studying historic photographs and engineering drawings at each of the Corps offices, the investigator met with engineers on the staff of each district.

The initial scope of work for the study called for visits to the Chicago and Atlanta regional branches of the National Archives. After discussing the holdings of these facilities with Martin Reuss of the U.S. Army Corps of Engineers Office of History, the investigator decided the lack of organization of these collections would make it difficult to ferret out useful information from the large amount of retained records.

Several other archival collections with holdings on the Ohio River were also not visited. These included the Inland Rivers Collection of the Cincinnati Public Library, the Mercantile Library of the University of Missouri at St. Louis, the library of the American Concrete Institute (suburban Detroit); and the Waterways Experiment Station, Vicksburg, Mississippi. The published catalog of the Inland Rivers Collection was studied. Few sources related specifically to the engineering of the navigation system and those that did were available elsewhere. The remaining three collections may prove to be useful repositories in any future research. The Mercantile Library has a complete indexed collections of the *Waterways Journal*, as well as historic files maintained by that publication. The library of the American Concrete Institute may contain publications that would help clarify and elucidate the early use of concrete in navigational lock and dam construction. Some reports of the Waterways Experiment Station were found and used at other repositories. The WES has, of course, a complete run of their reports, and additional reports may provide information on relatively modern technical innovations on the Ohio River Navigation System.

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Table 1-1. Ohio River Locks and Dams

Name	Location	River Mile	Locks Placed in Service	Removed from Service	Lock Sizes	Lift of Lock	Valve Number/Type	Dam Type
Davis Island (#1)	Border of Avalon and Bellevue, PA	4.7	October 7, 1885	1921	50 x 158	3.1 feet	14 filling and 14 emptying butterfly valves	1,223 foot navigable pass dam with 559 ft. Chanoine wicket pass and bear-trap weir. Stone-filled, timber crib back channel dam.
Emsworth	Emsworth, PA	6.2	August 13, 1921	n/a	110 x 600 (main) 56 x 360 (aux.)	18.0 feet	16 filling, 16 emptying; vertical butterfly	Movable crest; 13 vertical lift gates, **eight in main dam, five in back channel dam**; one Sidney gate **in back channel dam**
#2	Coraopolis, PA	9.0	October 13, 1906	1921	110 x 600	7.8 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with Chanoine wickets and bear-trap weir.
#3	Glen Osborne, PA	10.9	February 1, 1908	1929	110 x 600	7.7 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with Chanoine wickets and bear-trap weir.
Dashields	1.6 miles below Sewickly, PA	13.3	August 1, 1929	n/a	110 x 600 (land) 56 x 360 (river)	10.0 feet	horizontally mounted butterfly valves	Fixed crest dam (only one on the Ohio River).
#4	Legionville, PA	18.6	February 1, 1908	1936	110 x 600	7.6 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with Chanoine wickets and bear-trap weir.
#5	Freedom, PA	23.9	November 21, 1907	1936	110 x 600	8.5 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 700 foot long navigable pass, 96 foot long Chanoine weir and two 93 foot bear-trap weirs.
#6 (Merrill)	Beaver, PA	28.8	August 3, 1904	1936	110 x 600	5.7 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 600 foot navigable pass, 120 foot Thomas A-frame weir and two 120- foot bear-trap weirs.
Montgomery	1.4 miles above Industry, PA	31.7	June 25, 1936	n/a	110 x 600 (main) 56 x 360 (aux)	17.5 feet	6 horizontally mounted butterfly valve	Non-navigable movable crest with vertical lift gates.
#7	Midland, PA	36.5	September 16, 1914	February 15, 1961	110 x 600	6.9 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 600 foot navigable pass, 72 foot Chanoine weir and two 91 foot bear-trap weirs.
#8	Newell, WV	46.4	July 14, 1911	November 5, 1960	110 x 600	6.4 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 700 foot navigable pass, 200 foot Chanoine weir and two 91 foot bear-trap weirs.
New Cumberland	Strattonsville, Ohio	54.4	November 11, 1959	n/a	110 x 1200 (main) 110 x 600 (aux.)	20.5 feet	reverse tainter valves	Non-navigable movable crest with 11 tainter gates each with a clear span of 110 feet.
#9	New Cumberland, WV	56.1	November 2, 1914	November 28, 1960	110 x 600	7.4 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 600 foot navigable pass, 224 foot Chanoine weir and two 91 foot bear-trap weirs.
#10	Steubenville, OH	66.2	October 31, 1915	July 27, 1965	110 x 600	8.4 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 600 foot navigable pass, 256 foot Chanoine weir and two 91 foot bear-trap weirs.
#11	2.3 miles below Wellsburg, WV	76.9	August 1, 1911	December 26, 1964	110 x 600	7.3 feet	17 filling and 17 emptying butterfly valves on vertical axes	Navigable pass dam with 700 foot navigable pass, 120 foot Chanoine weir and two 91 foot bear-trap weirs.
Pike Island	2 miles above Warwood, WV	84.3	November 29, 1963	n/a	110 x 1200 (main) 110 x 600 (aux)	21.0 feet	steel reverse tainter valves; two in the small chamber; four in the large chamber	Non-navigable dam with five submergible and four non-submergible tainter gates.
#12	Warwood, WV (2.3 miles above Wheeling)	87.4	January 16, 1917	August 19, 1959	110 x 600	8.4 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 200 foot Chanoine weir and two 91 foot bear-trap weirs.

Table 1-1. Continued.

#13	McMechen, WV	96.1	August 1, 1911	February 6, 1960	110 x 600	7.3 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 632 foot navigable pass, 160 foot Chanoine weir, and two 83 foot bear-trap weirs.
#14	Woodland, WV	114.0	August 20, 1917	July 1961	110 x 600	8.3 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 136 foot Chanoine weir and two 91 foot bear-trap weirs.
Hannibal	1.6 miles above New Martinsville, WV	126.4	August 1971	n/a	110 x 600 (landward) 110 x 1200 (riverward)	21.0 feet	reverse tainter valves	1,098 foot non-navigable dam with 8 fixed trunnion non-submergible radial gates.
#15	New Martinsville, WV	129.1	July 1, 1916	1972	110 x 600	7.8 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 208 foot Chanoine weir and two 91 foot bear-trap weirs.
#16	Bens Run, WV	146.5	August 16, 1917	1972	110 x 600	7.8 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 160 foot Chanoine weir and two 91 foot bear-trap weirs.
Willow Island	2.7 miles above Waverly, WV	161.7	January 1972	n/a	110 x 1200 (main) 110 x 600 (aux)	20.0 feet	reverse tainter valves	Non-navigable, high-lift, gated dam with eight 28-foot high tainter gates, and 110 foot fixed weir.
#17	4.5 miles above Marietta, Ohio	167.5	August 1, 1918	1972	110 x 600	8.2 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 352 foot Chanoine weir and two 91 foot bear-trap weirs.
#18	4.7 miles above Parkersburg, WV	179.9	May 1, 1910	1965	110 x 600	6.2 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 300 foot Chanoine weir and two 50 foot bear-trap weirs.
#19	Little Hocking, Ohio	192.2	October 16, 1916	1965	110 x 600	7.7 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 688 foot navigable pass, 304 foot Chanoine weir and two 91 foot bear-trap weirs.
#20	Belleville, WV	201.7	January 16, 1917	1965	110 x 600	7.5 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 192 foot Chanoine weir and two 91 foot bear-trap weirs.
Belleville	.3 miles below Reedsville, Ohio	203.9	October 12, 1965	n/a	110 x 1200 (main) 110 x 600 (aux)	22.0 feet	reverse tainter valves	1,206 foot non-navigable, high lift, gated dam with 8 tainter gates and 189 foot fixed weir.
#21	1.4 miles above Portland, Ohio	214.6	September 5, 1919	1967	110 x 600	5.6 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 388 foot Bebout weir and 100 foot fixed weir section.
#22	Ravenswood, WV	220.9	December 1, 1918	1967	110 x 600	7.8 feet	17 emptying and 17 filling butterfly valves	navigable pass dam with 600 foot navigable pass, 240 foot Bebout weir, 91 foot bear-trap and 81 foot fixed weir.
#23	Millwood, WV	231.4	September 26, 1921	1967	110 x 600	8.1 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 240 foot Bebout weir, 91 foot bear-trap weir and 49 foot fixed weir.
Racine	1.5 miles below Letart Falls, Ohio	237.5	December 16, 1967	n/a	110 x 1200 (main) 110 x 600 (aux)	22.0 feet	reverse tainter valves	1,160 foot non-navigable, high-lift, gated dam with eight tainter gates.
#24	Graham, WV	242.0	August 27, 1919	1937	110 x 600	7.0 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 240 foot Bebout weir, 91 foot bear-trap and 65 foot fixed weir.
#25	5 miles above Pt. Pleasant, WV	260.0	1922	1937	110 x 600	9.0 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 252 foot Bebout weir, 91 foot bear-trap and 39 foot fixed weir.
#26	Hogsett, WV	278.0	August 1, 1912	1937	110 x 600	7.5 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 600 foot navigable pass, 272 foot Chanoine weir and two 91 foot bear-trap weirs.

Table 1-1. Continued.

Gallipolis (present Robert C. Byrd)	.7 miles below Hogsett, WV	279.2	1937 replacement locks: January 1993	n/a	110 x 600 110 x 360 replacement locks: 110 x 1200 110 x 600	Original: 26 feet Present: 23 feet	Original: tainter valves Replacement: reverse tainter valves	Non-navigable dam with eight roller gates, each measuring 134 feet 11 inches wide and 22 feet in inside diameter.
#27	3.6 miles above Proctorsville, Ohio	301.0	1923	1959	110 x 600	6.4 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 652 foot navigable pass, 288 foot Bebout weir, 91 foot bear-trap, and 97 foot fixed weir.
#28	3.3 miles below Huntington, WV	311.6	March 1, 1915	1959	110 x 600	7.1 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 296 foot Chanoine weir, two 91 foot bear-traps, and 70 foot fixed weir.
#29	2.7 miles above Ashland, KY (3 miles below mouth of Big Sandy River)	319.9	December 1, 1916	1959	110 x 600	8.0 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 124 foot Chanoine weir, and two 91 foot bear-traps.
#30	3.3 miles below Greenup, KY	339.4	1923	1959	110 x 600	7.5 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 120 foot Bebout weir, 91 foot bear-trap, and 144 foot fixed weir.
Greenup	4.9 miles below Greenup, KY	341.0	November 27, 1959	n/a	110 x 1200 (main) 110 x 600 (aux)	30.0 feet	reverse tainter valves	1,287 foot non-navigable high- lift, gated dam with 245 five weir and nine tainter gates.
#31	3.3 miles below Portsmouth, Ohio	359.3	October 22, 1919	1962	110 x 600	7.5 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 160 foot Chanoine weir, and two 91 foot bear-traps.
#32	1 mile above Rome, Ohio	382.6	1926	1962	110 x 600	7.5 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 100 foot Chanoine weir, two 91 foot bear-traps, and 340 foot fixed weir.
#33	3.5 miles above Maysville, KY	405.1	October 28, 1921	1962	110 x 600	7.0 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 216 foot Chanoine weir, and two 91 foot bear-traps.
#34	Chilo, Ohio	434.1	1925	1962	110 x 600	5.6 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 100 foot Chanoine weir, two 91 foot bear-traps, and 535 foot fixed weir.
Capt. Anthony Mendahl	2.2 miles above Foster, KY	436.2	November 1962	n/a	110 x 1200 (main) 110 x 600 (aux)	30.0 feet	reverse tainter valves	1,756 foot non-navigable dam with 12 tainter gates and 372 foot fixed weir.
#35	1 mile below New Richmond, Ohio	451.0	September 3, 1919	1962	110 x 600	6.4 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 208 foot Chanoine weir, two 91 foot bear-traps, and 255 foot fixed weir.

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Table 1-1. Continued.

#36	9.3 miles above Cincinnati, Ohio	460.9	1925	1962	110 x 600	7.9 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 100 foot Chanoine weir, two 91foot bear-traps, and 250 foot fixed weir.
#37	Fernbank, Ohio	483.2	1911	1959	110 x 600	7.8 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 200 foot fixed weir, and 3 bear traps of 78 feet each.
#38	McVille, KY	503.3	1924	1959	110 x 600	7.3 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 700 foot navigable pass, 100 foot Chanoine weir, two 91 foot bear-traps, and 259 foot fixed weir.
Markland	1 mile above Markland, IN	531.5	Locks in operation: May 1959 Dam: June 1964	n/a	110 x 1200 (main) 110 x 600 (aux)	35.0 feet	reverse tainter valves	1,395 foot non-navigable dam with 12 tainter gates, 7 originally submergible, 5 non-submergible.
#39	1 mile above Markland, IN	531.7	October 1921	1959	110 x 600	6.0 feet	17 emptying and 17 filling butterfly valves	Navigable pass dam with 800 foot navigable pass, 200 foot Bebout weir, two special wickets, 91 foot bear-trap, and 277 foot fixed weir.
Falls of the Ohio Locks (first)	Louisville, KY		December 23, 1830	1872	3 locks: 50 x 170			
Falls of the Ohio Locks (second)	Louisville, KY		February 26, 1872	1885	two locks: 80 x 348		hand operated butterfly valves turning on vertical axis	Movable dam with 11 sections of Boule gates, Chanoine wickets, and permanent masonry weirs.
#41	Louisville, KY	604.4	July 1885		110 x 600 56 x 300		hydraulically operated butterfly valves turning on a vertical axis	Movable dam with 1952 feet of Boule gates, 648 feet of Chanoine wickets and 2246 feet of masonry fixed weir.
McAlpine	Louisville, KY	Dam: 604.4 Lock: 606.8	Main lock: 1961 Intermed.: 1921 Aux.: 1930+ Dam: Sept. 1964	n/a	110 x 1200 (main) 110 x 600 (intermed.) 56 x 360 (aux.)	37.0 feet	reverse tainter valves	7,590 foot concrete fixed weir with nine tainter gates in 1,065 foot dam.
#43	3.3 miles below West Point, KY	633.2	June 13, 1921	1966	110 x 600	9.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 320 foot Bebout weir, and one 91 foot bear-trap weir.
#44	Leavenworth, IN	663.2	September 12, 1925	1966	110 x 600	9.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 140 foot Chanoine weir, 140 foot Bebout weir, and two 91 foot bear-trap weirs.
#45	Addison, KY	703.0	September 12, 1927	1996	110 x 600	9.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 800 foot Chanoine pass, 200 foot Chanoine weir, 100 foot Bebout weir, and two 91 foot bear-trap weirs.
Cannelton	3 miles above Cannelton, IN	720.7	Locks placed in operation: Dec. 1966 Dam completed: 1974 Official opening: November 2, 1974	n/a	110 x 1200 (main) 110 x 600 (aux)	25.0 feet	reverse tainter valves	Non-navigable dam with 12 non-submergible tainter gates in 1,395 ft. gated section; 195 foot fixed weir.

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Table 1-1. Continued.

Newburgh	16 miles above Evansville, IN	776.1	Locks placed in operation: Dec. 1969 Dam completed: 1975. Official opening: July 2, 1975	n/a	110 x 1200 (main) 110 x 600 (aux)	33.0 feet	reverse tainter valves	Non-navigable dam with nine non-submergible tainter gates in 1,140 foot long gates section and 1,300 foot fixed weir.
#46	Owensboro, KY	757.3	1928	1969	110 x 600	11.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 300 foot Chanoine weir, 100 foot Bebout weir, and two 91 foot bear-trap weirs.
#47	Newburg, IN	777.7	1928	1969	110 x 600	9.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 400 foot Chanoine weir, two 91 foot bear-trap weirs.
#48	5.8 miles below Henderson, KY	809.6	January 1, 1922 Dam: July 20, 1922	1969	110 x 600	9.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 800 foot Chanoine pass, 296 foot Chanoine weir, 304 foot Bebout weir.
#49	2.4 miles below Uniontown, KY	845.0	August 3, 1928	1969	110 x 600	11.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 200 foot Chanoine weir, 100.1 foot Bebout weir, and two 91 foot bear-trap gates.
Uniontown (John T. Myers)	3.5 miles below Uniontown, KY	846.0	Locks placed in operation: December 1969 Dam completed: 1977 Officially opened: October 4, 1975	n/a	110 x 1200 (main) 110 x 600 (aux)	22.0 feet	reverse tainter valves	1,265 ft. gated section with 10 non-submergible tainter gates and 2,239 ft. fixed weir.
#50	1 mile below Weston, KY	876.8	October 16, 1928	1979	110 x 600	10.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 300 foot Chanoine weir, 100 foot Bebout weir, and two 91 foot bear-trap weirs.
#51	.6 miles below Golconda, IL	903.1	July 30, 1929	1979	110 x 600	8.0 feet	17 emptying and 17 filling butterfly valves	Navigable dam with 900 foot Chanoine pass, 300 foot Chanoine weir, 100 foot Bebout weir, and two 91 foot bear-trap weirs.
Smithland	2 miles above Smithland, KY	918.5	Locks placed in operation: 1979 Dam completed: November 1980	n/a	110 x 1200 110 x 1200	22.0 feet	reverse tainter valves	Non-navigable dam with 2,140 ft. gated section with 11 non-submergible tainter gates and 1,375 ft. long fixed weir.
#52	1.4 miles below Brookport, IL	938.9	October 27, 1928 110 x 1200 foot chamber: 1969	n/a	Main lock: 110 x 1200 Aux: 110 x 600	12.0 feet	17 emptying and 17 filling butterfly valves	Navigable pass of 1,248 feet, 540 feet of chanoine weir, 160 feet of bebout weir, three 91-foot beartraps, and 725 feet of fixed weir.
#53	10.8 miles above Mound City, IL and 10.8 miles below Joppa, Illinois	962.6	August 27, 1929 110 x 1200 foot chamber: 1980	n/a	Main lock: 110 x 1200 Aux: 110 x 600	9.6 feet	17 emptying and 17 filling butterfly valves	Navigable pass of 932 feet, two 91 foot beartraps, 340 feet of chanoine weir, 160 feet of bebout weir, 302 feet of fixed weir, and 2,000 feet of fixed weir.
Olmsted	Olmsted, IL	964.6	Under construction (began 1993)	n/a	110 x 1200 110 x 1200	Reverse tainter valves		Navigable dam with 2,200 foot long navigable pass section made up of steel wicket gates; non-navigable section of 6 tainter gates.

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CHAPTER II

POLITICAL FACTORS AND MILITARY INFLUENCES ON THE DEVELOPMENT OF OHIO RIVER NAVIGATION IMPROVEMENTS

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INTRODUCTION

The political debates surrounding Ohio River Navigation improvements reflect changes in the national temperament. The evolution from untamed river to navigation system mirrored the transformation of political and popular thought of the nation, growing in sophistication, complexity, and scope as our government matured.

The debates and theories surrounding the U.S. Army Corps of Engineers' development of Ohio River Navigation present a microcosm of broader national trends and issues. National events figuring prominently into the discussion and development of river improvements included debates over the constitutionality of internal improvements in the early-19th century, Jacksonian Democracy's tendency to emphasize state's rights and authority, sectional issues that lead up to the Civil War as well as those in the post-war period, the agrarian and Granger movements, the Progressive Era, economic depression, and both World Wars. The successful completion of the Ohio River system of locks and dams by 1929 was never a sure thing, and owed its success largely to political maneuvering (often derided as "pork barrel politics"), fortuitous events including floods, wars, and timely political issues. Local Ohio Valley political and business organizations took advantage of these opportunities to pressure Congress, and slowly gained power enough to become a significant political force in the form of such organizations as the National Rivers and Harbors Congress and the more locally oriented Ohio Valley Improvement Association.

Alignments on the debate over river and harbor improvements tended to be more sectional than political, with the only possible exceptions being the Granger movement, which argued for better waterways and railroad regulation, and the early part of the Progressive Era, when Congressmen, predominantly the Progressive Republicans, used the conservation initiative to promote river navigation.

River improvements, especially those on the Mississippi, Ohio, and Missouri rivers, were nationally important concerns during the early twentieth century. The nature of the debate experienced a shift from issues over the constitutionality of federally sponsored improvements, to those of scientific answers to problems associated with rivers and harbors. The Progressives had a heavy reliance on science to solve these problems. This was a time of shifting roles for Congress, the Corps, and others involved in the debates over river and harbor improvements. Sometimes this change was so fast and drastic, that it left the players confused. All sides sought to use the findings of experts to strengthen their agenda. With its emphasis on conservation and trust regulation (mainly of the railroads), the movement became a vehicle for promotion of waterways improvements, and actually became part of the party platforms of the three major parties: Democrat, Republican, and Progressive Republican, or Bull Moose party. One may speculate as to whether the Ohio River Navigation System would have ever been a reality if not for the Progressives.

The history of the political debates over canalization of the Ohio River, and especially its link to flood control issues, largely supports Samuel P. Hays' theories concerning the professional nature of the Progressive movement. Professionals with expertise in soil and water conservation, navigation, and flood control rose to positions of power and respect as legislators looked to them for scientific answers to the issues before Congress. These professionals disagreed over the links between flood control and navigation, and the usefulness of locks and dams on the Ohio. These experts confused both Congress and the public, and many political leaders selected expert opinions that supported their political agenda.

Historians continue to debate the role of the Corps of Engineers within this political fray. Often, Corps leaders saw potential changes in national River Navigation policy as threats to their agency. Some historians, such as Samuel P. Hays and Frank E. Smith, have concluded that the Corps wielded too much power and criticized the Corps as obtuse, obstructionist, and self-serving as it fought potentially beneficial legislation such as that represented by the Newlands Bill of 1907. Although the Corps did struggle against what may have been useful legislation, and often contradicted itself in its professional opinions regarding the river and harbor projects it reviewed for Congress, this criticism appears harsh. The Corps' leaders were but one player in the political fray that included diverse forces of local and national politics as well as agency rivalries. The Bureau of Reclamation, the Forest Service, the USGS, and the Department of Agriculture all made attempts to wrest control of the rivers and harbors from the Army engineers. Although constantly arguing that it was a technical body and not political, the Corps excelled in this political game, eventually taking on the tasks of flood control, conservation, and river navigation.

HISTORICAL CONTEXT OF OHIO RIVER NAVIGATION IMPROVEMENTS

The politics of Ohio River Navigation improvement cannot be understood outside of the larger political debate during the 19th century on internal improvements. Accordingly, this study will begin with an overview of that debate in the context of Ohio River Navigation.

Between the American Revolution and the so-called "Era of Internal Improvements" of the early-19th century, private enterprise undertook most transportation projects. Some states, such as New Jersey, Maryland and Virginia provided aid through tax exemptions and purchase of stock. Most early improvements were roads. Turnpike companies constructing roads commonly raised money through the issuance of stock. Two companies, however, did construct early canals built without any public aid in the first decade of the 19th century. The Santee Canal, extending from Charleston, South Carolina, opened in 1800, and the Middlesex Canal connected Boston to Lowell Massachusetts on the Merrimack River in 1803. The Potomac Company, funded by both state and private funds, began river and canal improvements to the Potomac River in the same period. On the Ohio River, Kentucky and Indiana both began plans for a canal around the Falls of the Ohio at present-day Louisville (Goodrich 1960:20-21).

Serious thought to improving navigation on the Ohio River started at the beginning of the 19th century when in 1807, two waterway navigation improvements came before Congress: the Chesapeake and Delaware Canal and the proposed canal at the Falls of the Ohio. Henry Clay [Plate 2-1](Repub., Whig), Senator from Kentucky, introduced the bill for the Falls of the Ohio project. In a tactic not unlike the later omnibus river and harbor bills, he had joined Senators from Delaware in support of these two canal projects. John Quincy Adams (Plate 2-2) strongly opposed these measures as local projects that were unconstitutional. He warned that it was "fraud and collusion" for men to create a combination of interests to get their local issues through Congress. Adams instead introduced a resolution to have the Secretary of the Treasury submit a general plan for road canal and river improvements before approving singular projects. Congress agreed, defeating the two projects, and instead directed the Secretary of the Treasury to prepare a report on these projects for its next session (Goodrich 1960:27-28).

In 1808, Albert Gallatin (Plate 2-3) then Secretary of the Treasury, presented to Congress a "Report on Roads and Canals" (Gallatin 1808). In the report, he made observations on various completed and anticipated improvements. His conclusion: although many projects had been started, a large percentage had stalled for various reasons including mismanagement, personal problems, and above all, lack of available funds. He recommended federal government aid for the construction of over fifteen specific roads and canals, ranging from a turnpike from Maine to Georgia, Great Lakes inland navigation, and a canal around the Falls of the Ohio. He also stated that Congress should fund some local projects out of "justice". Gallatin estimated the total cost for all these projects at $20,000,000. He even suggested that the fund could be a revolving one, if Congress decided that the nation could not afford the debt (Goodrich 1960:30-31).

Gallatin had a strong understanding of American geography and an instinct for the country's future needs. Nearly all of his proposed improvements were eventually completed in the 19th century. Although his insight into the need and usefulness of the projects was remarkable, his thoughts on the ability of the nation to either finance or agree politically on any one improvement proved naïve. Gallatin did not see any issue about the constitutionality of the projects, and he assumed that the conflict of local versus national interests could be easily settled through what he termed "justice and policy" (Goodrich 1960:33). In fact, these two issues, constitutionality and

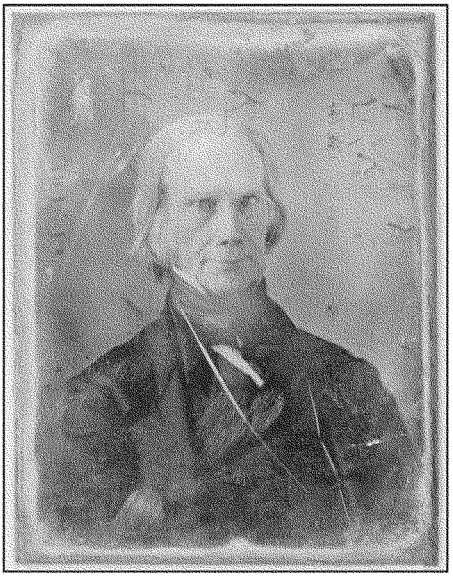

Plate 2-1. Henry Clay

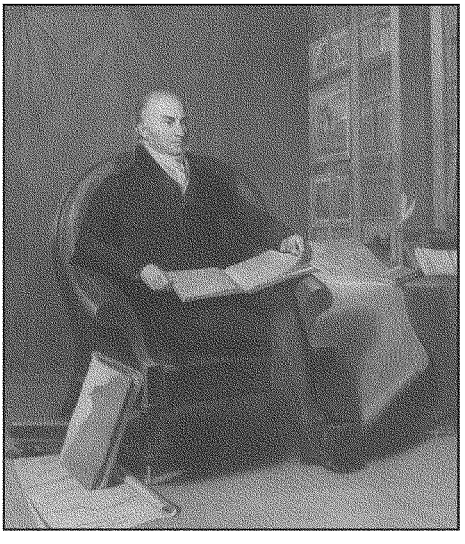

Plate 2-2. John Quincy

sectional rivalry, became the two chief impediments to almost every transportation improvement proposed well into the 20th century.

Gallatin's plan also assumed no other major government expenditures or financial problems in the near future, but interruptions in trade resulting from the Embargo Act of 1807 and the increased military expenditures leading up to the War of 1812 made funds scarce. The only federal appropriation for internal improvements came in 1809 with aid to construct the Carondolet Canal at New Orleans as a defense measure (Goodrich 1960:36). Upon the conclusion of the War of 1812, Congress once again took up the topic of internal improvements. John C. Calhoun [Plate 2-4](Dem.) of South Carolina submitted a bill to set aside federal income from the newly chartered Second Bank of the United States as a fund for internal improvements. National vs. state interests immediately came into play. Although conceived as a measure giving Congress the authority to decide where the money was spent, as passed, the money went directly to the states in proportion to their population, thereby almost ensuring that little of national interest, other than by pure chance, would come of any project. Clay, hoped to secure money for the canal around the Falls of the Ohio, since such a project would benefit his region. To that end, he added a proviso to the Act that a state could request that its share of the appropriation be given to a border state. This would give Kentucky the advantage of combining its money with that of the future state of Indiana when constructing a project of common interest such a the canal. Ultimately, however, the bill failed under a veto from President James Madison (Goodrich 1960:37-38).

In 1819, Calhoun, as Secretary of War, presented a plan of internal improvements stressing military importance. Although similar to Gallatin's plan, it extended farther west. Eventually, these recommendations evolved into the General Survey Act of 1824, but the question of whether the federal government had the authority to improve and regulate waterways remained open. Todd Shallat, in his book *Structures in the Stream*, explains that the 1824 Supreme Court case *Gibbons v. Ogden* became an important factor in the passage of the General Survey Act. This case involved the legality of a state to control exclusive rights to a ferry operation between New York and New Jersey. Daniel Webster, council for the steamboat operator, argued that no state monopoly could infringe upon the authority of Congress to regulate trade, and by inference, Congress had jurisdiction over all inland navigation. This case, according to Shallat, sent the message to Congress that legislation such as the General Survey Act of 1824 was constitutional (Shallat 1994:125-126).

The General Survey Act gave the President power to order surveys for canal and road routes having national importance. Specifically, this law authorized the President of the United States to "cause the necessary surveys, plans, and estimates to be made of the routes of such roads and canals as he may deem of national importance, in a commercial or military point of view, or necessary for the transportation of the public mail" (4 Stat. L., 22 as quoted in Holt 1923:5). This law also provided for civil engineers, as well as officers of the Corps of Engineers to carry out the work. Although Congress repealed the Corps' authority to employ civil engineers in 1838, the Army engineers continued in this work.

To carry out the General Survey Act, Congress formed a Board of Engineers for Internal Improvements within the Corps. The board consisted of General Simon Bernard and Colonel Joseph G. Totten (Plate 2-5) of the Corps of Engineers, and John L. Sullivan, a civil engineer. The Board initially tried to think and act on a national scale, but due to already growing sectional interests and local political power, Congress approved appropriations on a haphazard basis with no consistent or comprehensive plan. The earliest works on the Ohio River were piecemeal contracts to remove snags on the river (Holt 1923:7). The Board served as the nation's planning instrument for internal improvements until 1831 (Hill 1957:57).

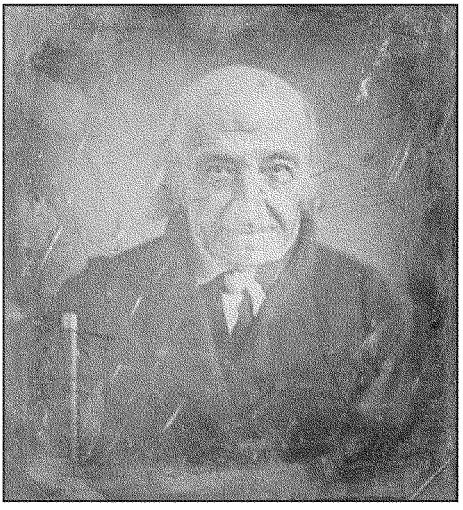

Plate 2-3. Albert Gallatin

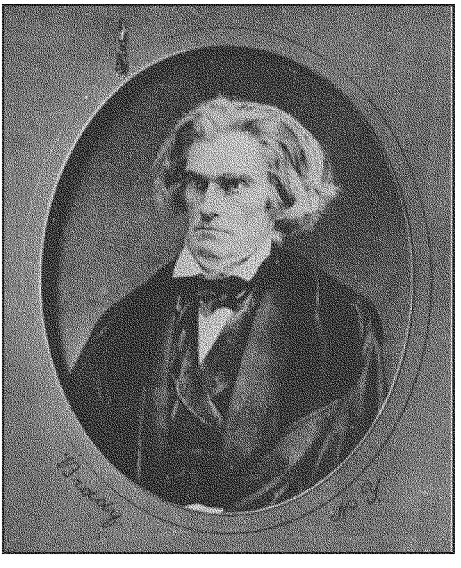

Plate 2-4. John C. Calhoun

In 1824, Congress also passed the first river-improvement bill and a separate harbor improvement bill, but legislation specifically directed at rivers and harbors improvements did not come until two years later, when in 1826, Congress passed the first "River and Harbor Bill" (Holt 1923:5-6). As with the General Survey Act of 1824, much of the money appropriated under the 1826 River and Harbor Act found its way to local and secondary projects as sectional pressures became dominant. As the country expanded, the task of satisfying all requests for aid became impossible. The Army engineers had an increasingly difficult time distributing the work in a way that would not cause sectional jealousy or charges of favoritism. Conflicts of state and sectional interests not only increased the demand placed upon the engineers, but also caused the work to become more fragmented. The army began to emphasize smaller, more scattered improvements to satisfy these factions, and as a result, the improvements ceased to be national in scope. Congressmen tended to support appropriations only if advantageous to their own sections, and the army engineers generally supplied the needed services (Hill 1957:76). Congress received a great deal of criticism for its piecemeal approach to these appropriations, and the Army engineers often complained about small and late appropriations. Logrolling, sectionalism, inefficient and useless projects were common complaints (Hill 1957:179).

More effective aid for the Ohio came from Congress in the form of federal subscription to stock of private improvement companies. Many in Congress felt that the government's money would be spent more wisely if private investors also had a stake in the outcome. The privately owned Louisville and Portland Canal received funding from Congress in this manner in the amount of $100,000 in May of 1826 (Goodrich 1960:40). The canal, completed in 1830, permitted vessels to bypass the treacherous Falls of the Ohio, was a major cause for Louisville's success (Bigham 1998:84-89).

Federal internal improvements studies focused more on surveys for canals and roads than river improvements in the early years. The engineers made surveys for the Chesapeake and Ohio, the Ohio and Lake Erie, and other canals, as well as routes for the new national road. In 1827, the Topographical Engineers began to survey a route for the Baltimore and Ohio Railroad under the justification that the proposed railroad was of national importance (Hill 1957:58-60, 70). During this period, both James Monroe and John C. Calhoun proposed an increase in the number of Army engineers available to assist in internal improvements. President John Quincy Adams and Secretary of War James Barbour supported the call for government sponsorship of increased aid to internal improvement planning (Hill 1957:62). In 1829, Major John J. Abert, head of the Topographical Bureau of Engineers, criticized the Board of Internal Improvements for inefficiency. As a result, Abert managed to get himself placed on the Board to coordinate its operations. Between 1831 and 1838, the Topographical Bureau of Engineers, which was in general responsible for internal improvements, administered the General Survey Act. Still being geared toward aiding local and private enterprises, the General Survey Act soon lost its Congressional support and authority. During the 1830s, the emphasis on canals decreased and focus turned to roads and railroads while public aid justification became increasingly military due to westward expansion (Hill 1957:80).

President Andrew Jackson supported a river and harbor development policy for any improvements that were of national scope. For that reason, he favored works on the Ohio and Mississippi since they could aid foreign trade. Although Jackson agreed in principle to aid for national improvements, he renounced his power under the General Survey Act to initiate such studies, leaving it up to Congress. In addition, struggles between those who believed that only military engineers should work on improvements under the Act prevailed against those who believed that civil engineers should also work on national internal improvements. Thus, civil

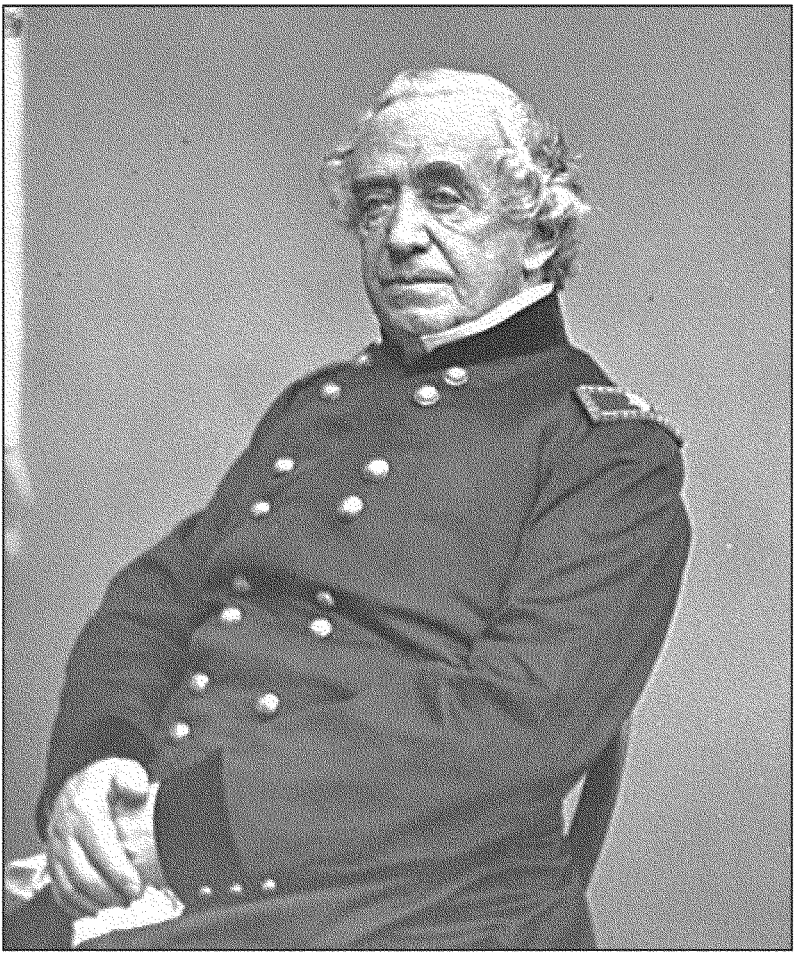

Plate 2-5. Col. Joseph G. Totten

engineers were barred from employment under the Act. Additionally, the Department of War restricted the Army engineers from aiding private and state enterprises when time permitted after 1836 (Hill 1957:83). In 1838, Senator James Buchanan summarized this sentiment when he argued that engineers were no longer scarce and Army engineers employed by canal and railroad companies had profited, while government projects had suffered (Hill 1957:92-93).

The doctrine of states' rights, sectional controversies, the loss of the planning functions under the Act, the growth of the railroads, rivalries between the President and Congress, Jackson's veto of federal aid to non-federal transportation projects, the financial panic of 1837, inadequate funds, increasing availability of civil engineers for private and local enterprises, and new military needs all contributed to the decline of Congressional support of the General Survey Act during the 1830s.

Jackson believed that the states could best administer funds for improvements. Congressional debates centered around the constitutional issues of the limits of federal power and state sovereignty. States generally opposed yielding on matters that would threaten their power base. Power to control the purse was the heart of the issue. Every state wanted money for improvements, but under their own control. Each Congressmen looked for the supreme benefit for their state. The ensuing rivalries between the states created inflexibility and impasse, paralyzing Congress and preventing major action. Congressmen complained that they could not obtain votes for their projects from outside of their region. This was doubtless exacerbated by the realization that funds were scarce and if one measure was approved, another state's issue would have to wait.

Although Jackson generally disapproved of federal action, other politicians from the West, including Senators Henry Clay and James Breckinridge of Kentucky, and Andrew Stewart (Repub., Whig) of Pennsylvania all argued strongly for improvements to the Ohio and were somewhat perturbed that the Congress constitutionally created "banks for the accommodation of the merchant" but would not "construct canals for the benefit of the farmer" (Goodrich 1960:46).

Additionally, those states that had already spent their own funds for improvements did not want to see states that had not had such expenses get federal money. New York, and the New England states had already funded their own projects. The North and South also had sectional disagreements, which grew on account of the slavery issue, splitting the Whig Party and diminishing solidarity on the internal improvement issue (Shallat 1994:153). The result of these rivalries was that the only money appropriated for many years was that which was secured as special acts or riders to other legislation (Hill 1957: 195-196).

After 1838, appropriations for river and harbor improvements decreased due to increasing political and constitutional criticism. In 1839, the War Department ordered the Engineers to restrict, and if possible suspend all improvements due to the lack of Congressional appropriations (Hill 1957:181). Congress passed no general river and harbor bill between 1838 and 1844. After 1838, legislators could not reach a consensus on the constitutionality or expediency of internal improvements. Congress never agreed on the scope of the river and harbor work, or how to define national vs. local work. Although Whigs were more apt to support and Democrats to oppose large improvements to the rivers and harbors, this cannot be stated as a general rule, as sectional differences often overruled party doctrine in the internal improvement debate. Western state Democrats favored major federal involvement for rivers and harbors. With so many opposing views and rivalries, Congress either defeated or the president vetoed most appropriation bills (Goodrich 1960:266; Holt 1923:9; Hill 1957:57).

Ohio River improvements remained at a virtual standstill during the administrations of Van Buren, Polk, and Pierce. In 1842, Congress made limited appropriations in the amount of $100,000 for the improvement of the Ohio, Mississippi, Missouri, and Arkansas rivers for the removing of snags, rocks, and wrecks, as well as some surveying. President Tyler and his Secretary of War William Wilkins recommended large improvements to western rivers and harbors with the condition that these be of demonstrably national character (Hill 1957:183). Disagreeing with Congressional efforts to fund small, sectional projects, Chief of Engineers Colonel John Abert refused to oblige Congress' requests for estimates on small projects, as he felt them to be inefficient and uneconomical. This situation continued during the war with Mexico. The new president, James K. Polk, held the opinion that all internal improvements were unconstitutional. Combined with the lack of consensus in Congress, this ensured no river and harbor appropriation bills through the year 1851 (Hill 1957:185-186).

Renewed appropriations came under President Millard Fillmore who approved of federal aid for internal improvements. He even approved of projects that appeared local in scope, such as the ship canal at Sault Ste. Marie, since he considered it to have national benefits. In 1852, Congress appropriated over $2,000,000 for over one hundred projects (Hill 1957:186).

At this time, the War Department divided the river and harbor works between the Topographical Engineers and the Corps of Engineers, with improvements to the western rivers and Great Lakes going to the Topographical Bureau, and the Atlantic and Gulf coasts being under the supervision of the Engineer Department. Chief Engineer Joseph Totten directed both groups to categorize each project based upon its national importance and to provide estimates and plans. Totten also assumed that his engineers had the power to originate estimates for new projects and present them to Congress.

In the 1850s, Secretary of War Jefferson Davis ruled that each project must be completed with existing appropriations, and that projects should not be planned with the expectation of future monies. This decree severely limited the size and scope of improvements. Davis also forbade improvements to commercial harbors and limited navigable river improvements to those "washing several states" as they alone had national importance. He expected local sources to fund local projects (Hill 1957: 190-191).

EARLY COMMUNITY GROWTH AND LOCAL POLITICAL INFLUENCE

From the earliest days of settlement in the Ohio Valley, merchants, manufacturers, and other more wealthy townspeople controlled the political leadership of their communities. The more successful merchants exercised the strongest control, while newspaper editors, lawyers, and doctors tended to have a lesser degree of control (Wade 1959:78). These community leaders understood that a town's growth depended upon its reputation for healthfulness, susceptibility to floods, their perceived future, as well as their natural resources. This knowledge caused them to be strong supporters of internal improvements (Bigham 1998:84). Secretary of the Treasury, Albert Gallatin, author of the "Report on Roads and Canals," had strong business interests along the Monongahela River that would benefit from efficient navigation of the Monongahela, Ohio, and Mississippi Rivers.

In these early days, professional men, including doctors, lawyers, ministers, teachers, and journalists, also held places of respect and standing in the community. Many of these professionals also had business interests (Wade 1959:113). Generally, the wealthy grew wealthier, due to the availability of cheap land and opportunity. They were proud of their achievements, and were often ostentatious about it. These merchants were the spokesmen for Federalism in the West, even after the party had all but died out in the East (Wade 1959:112).

In the early years of settlement, wage earners enjoyed relatively good pay and working conditions due to labor shortages, although this tended to be the case more north of the Ohio where slavery was not an issue (Wade 1959:117-119). European immigrants tended to settle north of the Ohio due to the presence of Slavery in the South. Among all immigrants, Germans were by far the most numerous (Bigham 1988:109). Transient workers, including wagon drivers, boatmen, and others, tended to be rough, causing trouble, and having no lasting interest in the community. In the early years of settlement of 1800-1820, this group was a prevalent, troublesome component of the population, but their numbers declined during the early 1820s, however, a new group of transient workers appeared on the scene with the construction of the Louisville and Portland Canal. By 1827, the transients comprised almost 10-percent of the population of Louisville (Wade 1959:117-218). By the 1830s, the lower classes began to exercise some political influence, and their associations began supporting candidates (Wade 1959:216).

Steamboating increased between 1811 and 1830 due to improvements on the river that included snag removal, dredging, and the important bypass around the Falls, the Louisville and Portland Canal. The steamboat trade that so dominated the river influenced the character of growth of the river towns began to lose its momentum upon the arrival of the first railroads in the Ohio Valley (Reid 1991:120). Still in the heyday of the steamboat, cities and regions urged Congressmen to secure river improvements of local and regional benefit. In 1850, frustrated with the lack of support in Congress, a group of businessmen in Evansville passed a series of resolution requesting funds for federal aid. In 1857, this group, chaired by entrepreneur John Law, promoted the study conducted by Charles Ellet who proposed a series of reservoirs on the Ohio in order to provide a six-foot navigation channel year round. The convention stressed the national character of such improvements (Bigham 1998:118).

An example of how river towns acted to promote navigation improvements, Evansville increased their efforts to persuade Congress after the Civil War when industry was on the rise. In September of 1868, the Evansville City Council sent one of its members as a delegate to a Cincinnati meeting with a congressional delegation with interests in the Ohio and Mississippi Rivers. They laid the foundation for the 1872 Cincinnati Chamber of Commerce convention

which stressed the increasing development of coal and iron, and planned more meetings as a means of securing congressional aid (Bigham 1998:119).

The ability of towns and cities to have access to river transportation had profound impacts on their social and economic development. Both the railroads and river transportation were important to the economy and society of the river valley. The very railroads that began to supersede the river in importance in the latter half of the 19th century also owned much of their growth to the river, and for a while the two modes of transportation appeared to be truly complementary. As river transport became more efficient and reliable, new markets for goods opened up, changing the nature of both product and production. Along the Lower Ohio, Tell City became quite prosperous in the late 1800s, and Cannelton was moderately prosperous. Flooding, however plagued Tell City, Cannelton, Evansville, Paducah, Mound City, and especially Cairo, and limited each city's success at attracting industry. Flooding also gave a city a reputation for unhealthfulness (Bigham 1998:177).

Nineteenth century river trade peaked in the 1850s. The steamboat was in its golden age, and although the railroads threatened river trade, it also complemented river trade by bringing inland goods to the river ports. Steamboat service continued to have the advantage of capacity and cost. Even the minimal navigation improvements at the Falls of the Ohio accelerated growth of some towns. New Albany, for instance, was located just below the falls, and took advantage of this location to become an important shipbuilding center, while rail and road service gave the town access to the interior for manufacturing industries. Other towns, such as Newburgh, experienced little growth despite its location on the river (Reid 1991:151; Bigham 1988:111).

Despite the lack of river improvements, larger, better situated communities did grow. Evansville and Paducah became urban centers in the late 1800s. Evansville became a large shipbuilding center, and was responsible for a large number of "tin clad" ships used by both North and South during the Civil War. Among the many ships was the U.S.S. Indianola (Plates 2-6 & 2-7). Mount Vernon, the sixth largest city on the Lower Ohio, grew steadily since 1870, as did Metropolis. Railroads became a major catalyst for the growth of these cities, although barge traffic began to play a role at the end of the 19th century (Bigham 1998:192).

DECLINE OF THE RIVER TRADE AND GROWTH OF RAILROADS

The Ohio River trade declined as promotion and aid to the railroads increased. Railroads built lines parallel to the river and the brief but promising era of river improvements seemed near its end (Bigham 1998:177). In 1850, no railroad offered serious competition to the Ohio river, the Mississippi, or any tributary, but this did not last. In 1847, Cincinnati had a new rail connection with Lake Erie at Sandusky and within four years, another connection to Cleveland. By 1854, Cincinnati had a second direct link to the East with the opening of the Ohio Central Railroad. In 1850 rail lines connected Madison, Indiana to Indianapolis and to Lake Michigan by 1854. In the 1850s, railroad mileage of the entire country tripled, becoming serious competitors for Ohio River commerce. By 1860, Pittsburgh, Cincinnati, and Louisville all had competent rail service, signaling the demise of the steamboat era (Hunter 1949:484-485). One by one, lesser river towns obtained connections to the railroad network. By 1887, only three of thirty major towns between Pittsburgh and Cairo had no railroad connection (Hunter 1949:587). Railroads had the advantage of speed, whereas river freight had the advantage of lower cost, however the rates often approached nearly equal levels in times of restricted navigation, especially in winter and low water, and the railroads enjoyed the further advantage of uninterrupted service (Hunter 1949:493).

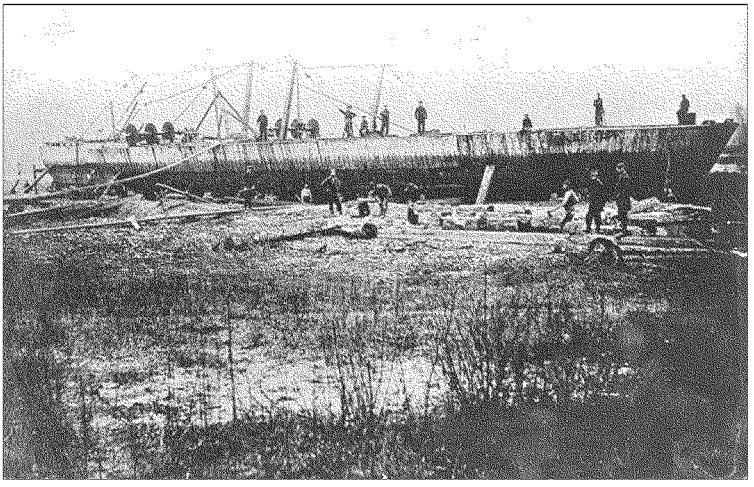

Plate 2-6. U.S.S. Indianola During Construction in 1862

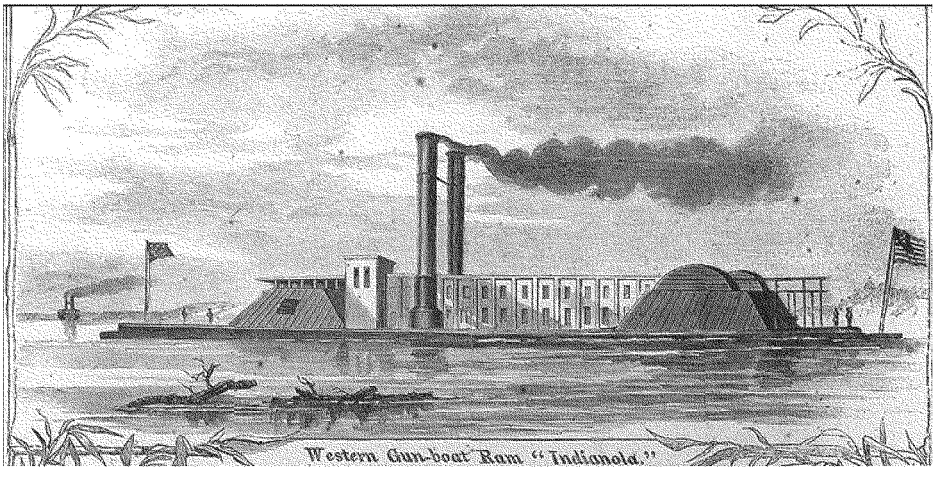

Plate 2-7. U.S.S. Indianola in 1863

POLITICS OF THE OHIO RIVER SLACKWATER SYSTEM: THE DAVIS ISLAND LOCK AND DAM

Samuel P. Hays, in his book *Conservation and The Gospel of Efficiency, 1890-1920*, argues that the Conservation Movement of the Progressive Era gained its momentum from a rising group of professionals who, as experts in their field, moved into positions of power in government and promoted their science. Hays argued that the movement was one of expert vs. expert, rather than a popular movement of workers against monied trusts and conservation minded people against wholesale destruction of our environment. According to Hays, professionals promoted conservation as an efficient use of resources, and not out of pure concern for the earth. In the process, professional rivalries and differing scientific opinions and theories often collided. The fervor with which these professionals pursued their vocations proved both an asset and liability. The conflicting expert opinions confused Congress and the public, and ultimately, both lost interest in the cause.

While the debate over canalization of the Ohio River, and especially its link to flood control issues, supports Hays' theories of the professional nature of the movement, the record also makes clear that there was a true grassroots movement component. Although it is true that the experts confused both Congress and the public, Congressional leaders, as well as local politicians and newspapers clearly selected expert opinions that would support their needs.

Hays indicts the Corps as an obtuse organization that fought comprehensive organized conservation. He argues that the Corps feared that an integrated water program that included conservation and reclamation would undermine their work and other agencies would usurp the Corps function. The Corps fought to block passage of the Newlands Bill of 1907 which sought to authorize comprehensive river development. Hays cites several articles appearing in *Engineering News* by Marshall O. Leighton of the U.S. Geological Survey, Brigadier-General Mackenzie, Hiram M. Chittenden, and others of the Corps of Engineers. While Leighton supported theories of reservoir and forest cover as important to flood control, the men of the Corps attacked the ideas. Part of the opposition stemmed from a desire for autonomy, but also from a desire to protect Congress' power to select public works projects rather than have a commission do the job. In the end, Hays asserts, the Corps entered the field of flood protection out of self-defense, forced to cultivate legislators and Congress used the guise of improvements to navigation to keep flood protection projects from appearing unconstitutional (Hays 1959:199-211).

The push for slackwater improvements to the Ohio River came from industrialists looking for cheap transportation alternatives to the railroads, and not primarily from river men. During the extreme seasonal dry spell and ensuing economic recession in 1871, Pittsburgh business interests began to organize a campaign for navigation improvements through year-round depth control of the city's harbor. The river became un-navigable from May until November of 1871. Coal shortages downstream in Cincinnati, Louisville, Evansville and Paducah became serious, driving up prices. In the winter of 1871 over ninety separate firms signed a petition to Congress for locks and dams. Signatories included General James K. Moorhead, who owned the Moorhead Iron Works. Moorhead was also president of the Pittsburgh Chamber of Commerce and the Monongahela Navigation Company (Johnson 1985:43).

The iron and steel industry promoted locks and dams but coal shippers opposed them. Due to this opposition, Colonel William E. Merrill could not seriously consider the problem from 1871 to 1878. After receiving the petition, Merrill asked for views of the coal shippers and rivermen in order to assess their objections to river improvements. He found many of their concerns

legitimate, including the request that the dam have a chute at least 300 feet wide to allow the passage of coal tows without lockage. In 1872, a convention of business associations organized by Felix R. Brunot and James Moorhead met in Cincinnati at which Captain Merrill described the proposed plans for the river navigation improvements to the Ohio. At this convention, the governors of seven states along the Ohio appointed a 35 member Ohio River Commission charged with keeping a vigilant watch on progress towards the improvement of the Ohio. James K. Moorhead became President and Chairman of the Commission (Johnson 1985:20-24).

After W. Milnor Roberts completed his report on canalization of the Ohio, state governments on the river made concerted efforts to gain congressional support for the project. On February 9, 1872, the Kentucky legislature instructed its Congressmen to support the matter. Kentucky, Pennsylvania, Indiana, Ohio, West Virginia, Illinois, and Tennessee all participated in the regional Board of Commissioners for the Improvement of the Ohio River (Ohio River Commission). The members studied the economic and transportation situation on the Ohio Valley, met with Army engineers, and lobbied Congress actively in support of the project (Johnson 1975:160). Coal interests who opposed the project cited that the dams might increase flood heights, that stagnant slackwater would foster disease, and that the river channels would fill with silt. The Monongahela slackwater system proved the first two concerns false. To the allegation of increased flood risk, the engineers proposed movable Chanoine dams similar to those constructed in France (Johnson 1975: 162).

Congress appointed General Godfrey Weitzel of the Louisville District of the Army Corps of Engineers and Colonel William E. Merrill of the Cincinnati District to a special Board of Engineers to report on the proposal in 1872. They recommended that Congress approve the project along with the offer of the Monongahela Navigation Company to pay for half of the experimental hydraulic gate designed by Felix R. Brunot of Pittsburgh. Due to opposition from coal shippers to the concept of restricting navigation with locks and dams, Congress did not act (Johnson 1975:162). These coal interests feared that the federal government might impede the coal industries use of the river and restrict access to their markets.

Engineers continued to argue the merits of water and rail transportation in professional circles. Captain F. A. Mahan published an article in *Transactions,* the journal of the American Society of Civil Engineers in 1893. The article, initially prepared for the International Engineering Congress of the Colombian Exposition of 1893, compared rail and water transportation with the object of showing that competition of water transportation kept railroad rates down, and would prove an efficient and economical mode of transportation if "brought up to date" like the railroads (*Transactions* Vol. XXIX, 1893. American Society of Civil Engineers, New York). In the next volume of *Transactions,* C. W. Raymond, Edward P. North, and F. A. Mahan published a discussion on Mahan's paper where Raymond and North take issue with Mahan's assumptions that water transportation is inherently cheaper than rail (*Transactions* Vol. XXX, 1893 American Society of Civil Engineers, New York) .

River transportation received national attention in 1872 at the request of President Ulysses S. Grant in his annual message. On the Congressional level, the Senate Committee on Transportation-Routes to the Seaboard (the Windom Committee) held hearings on the proposed Ohio River Canalization Project in 1873 and 1874 (Johnson 1975:165). The Senate formed the committee to set forth a planning policy for national waterway improvement. This Senate Select Committee on Transportation-Routes to the Seaboard was commonly called the Windom Committee since its chairman was Senator William Windom of Minnesota. Representing the Ohio Valley interests were Senator John Sherman (Repub.) of Ohio, Henry G. Davis (Repub.) of West Virginia, and John H. Mitchell (Repub.) of Oregon, a native of Western Pennsylvania

(Johnson 1985:30). The Committee's recommendations included a system of locks and dams on the Ohio that would maintain a depth of at least six feet, considering it "one of the most important works for which the National Government can appropriate money" (Johnson 1985:31).

Senator William Windom was originally from Mount Vernon, Ohio. Although chiefly interested in the Mississippi River and St. Lawrence, he supported all river and harbor improvements. He argued that the railroads could not effectively move cheap and heavy farm products as well as waterways. Before a bribery scandal forced him to resign in 1876, former Secretary of War William W. Bellknap had supported the idea of a "general system and plan" for improvements in Congressional hearings. He hoped to change the course previously set by Congress of funding small amounts for multiple projects. (Congressional Record, Senate, 45th 2nd 1878).

Proponents of the Granger Movement dominated the Windom Committee. This group had an interest in providing cheap transportation for agricultural products as a way to break the farmer's dependence on the railroads. Most farmers felt that the railroads discriminated against them in their pricing policies. Among the chief causes of the Granger Movement were the declining prices of farm products, a growing indebtedness of farmers to merchants and banks, discriminatory freight rates imposed on farmers by the railroads, and the acquisition by the railroads of public lands that formerly had served pioneer farmers as a source of new farmland. As a result, a number of political parties, bearing such names as the Reform Party and Anti-Monopoly Party, sprang up in several states during the 1870s and 1880s. These parties succeeded in electing several state officers and U.S. Senators. In a number of states, including Illinois, Iowa, Minnesota, Wisconsin, and California they contributed to the passage of laws regulating railroad rates and practices.

During the Windom Committee hearings, Colonel Merrill and Captain Milton B. Adams, deputy to General Weitzel testified. The Committee reported that although the railroads had been completed from the Ohio Valley to the Gulf, the waterways were still the "cheapest line of transport" and that the competition they provided would force rail freight rates down. The Committee recommended that Congress approve the Davis Island Dam project.

Congress approved $100,000 for initial land acquisition and construction at Davis Island in 1875, but the Pennsylvania legislature still needed to grant jurisdiction of Davis Island to the federal government. Local rivermen were not generally in favor of the measure, as it represented an unknown variable in the future of their business. Thus, few groups in the Ohio Valley promoted the improvement, although some, such as the City of Lawrenceburg, Indiana, petitioned the committee on Rivers and Harbors for river improvements (Congressional Record, House 48th 1st 1884). Outside of the Ohio Valley, the agrarian movement brought diverse interests together in support of river improvements, and Congressional supporters included Representatives Strother M. Stockslager (Dem.) of Indiana, William Breckinridge (Dem.) and Albert Willis (Dem.) from Kentucky, Thomas Bayne (Repub.) of Pennsylvania, and even Edwin Conger (Dem.) of Iowa and Richard Coke (Repub.) of Texas.

The political conflict between the iron and the coal interests had considerable influence on the engineering design of the Davis Island Dam, and by extension of that system to the other locks and dams. The conflict significantly altered the design of the entire navigation system. Frederick A. Mahan, Engineer in Charge, and Colonel Merrill investigated many systems in use both in the United States and Europe. In France, Merrill discovered the Chanoine system of rectangular panels called wickets that could be raised during low water periods, and lowered during flood stages in order to let boats through without using the lock. This was precisely what he needed on the Ohio to accommodate both the iron and coal interests (Johnson 1985:38-40).

Coal interests impeded construction of the dam despite the compromise in design. The U.S. Government needed to purchase a strip of land on the north bank of the river for a lock and lock house, as well as land for other structures associated with the dam. Coal shippers and their associates owned much of this land. Captain Thomas Mulvehill, a coal shipper owned one parcel. He used his property for barge moorage. Mulvehill demanded a high price for his land. David Davis, owner of the upper end of Davis Island, refused to sell altogether. Mrs. James Graham, who owned the land on the south bank also resisted. Eventually, Merrill settled with all parties, but at prices exceeding the value of the land, and at the loss of valuable time. Partly due to this delay, Merrill had to agree to construct only one dam at Davis Island, and wait for it to prove effective before continuing with the entire navigation system to Wheeling that he had originally proposed (Johnson 1985:50-52).

In their efforts against Ohio River canalization, the coal shippers tried to block the granting of jurisdiction over Davis Island in the Pennsylvania Legislature, and they were successful for several years from 1874 through 1877. In 1874, the Pennsylvania assembly passed the jurisdiction bill, but the Governor vetoed it, and in 1875, the legislation died in the state Senate. In 1877, the Pittsburgh Chamber of Commerce and the strong influence of the Ohio River Commission won out, and the enabling legislation passed (Johnson 1975: 165).

Joseph Stone (Repub.), Representative from Iowa gave a state of the Union speech on June 4, 1878, in which he derided the practice of granting land to the railroads (railroad subsidies) as "careless, wasteful and extravagant." Using the Mississippi Valley as an example, he asserted that the interests of the nation would be "more effectually promoted by improving . . . navigation." Harry White (Repub.) of Pennsylvania promoted a similar theme on May 11, but White continued by saying that this "mischief" of large companies combining to drive out all competition was rampant, extending to Standard Oil, the Southern Improvement Company, and others (Congressional Record, House 45th 2nd 1878). Although little concrete action came from this agitation immediately, it eventually led to the creation of the Interstate Commerce Commission in 1887, after the 1886 Supreme Court decision, *Wabash, St. Louis and Pacific Railroad* v. *Illinois*, ruled that the states could not regulate interstate railroads, effectively shifting the burden of regulation to the federal government.

Congress continued to struggle over successive river and harbor bills. In 1882, appropriations had increased over seven million dollars from the previous year. President Chester Arthur vetoed that year's appropriation bill (H. R. 6242) on the grounds that there were too many projects that appeared to be local in nature, and he could not approve measures that did not promote "the common defense or general welfare and . . . commerce among the States" (Chester Arthur's veto message as quoted in Congressional Record, Senate 64th 2nd 1916).

Where politics often failed, floods succeeded. When disastrous floods struck, Congressmen, eager to get money for flood control that many thought to be unconstitutional, linked the flood control projects to navigation improvements, making appropriations for navigation projects easier for Congress to agree on. Major floods in 1883 and 1884 caused Congress to appropriate funds for relief of flood victims and authorize some flood control projects, but many felt that it was time for Congress to authorize a study for a comprehensive system of flood control. *Engineering News*, in 1884, asserted that the Corps should undertake such a study, but Congress was not prepared to authorize it (Johnson 1975:192).

Congress did, however, allow for the study of levee projects for areas that had been severely damaged during the flood of 1884, and appropriated money for constructing a levee at

Jeffersonville as part of the 1884 Rivers and Harbors Act. Flood control was not specifically mentioned in the Act as it was not politically expedient, and the work was done under the guise of improving navigation (Johnson 1975:192). Other towns in Indiana and Illinois, including Lawrenceburg and Shawneetown had also been greatly effected during the floods, and Colonel Merrill of the Corps requested money for these towns despite the fact that the levee improvements would not aid navigation. Congress, although it would not commit to improvements for flood control, did approve monies for these improvements (Johnson 1975:192). Levees were often justified in terms of aiding navigation, such as when Congress funded embankment construction at Lawrenceburg, Indiana in 1886 to prevent the formation of bars which might obstruct navigation (Johnson 1975:192).

When the Davis Island Dam was completed in 1885, its successful operation transformed the coal shipper's previous objections into enthusiasm for extensive canalization. In July of 1888, this enthusiasm was reinforced, and virtually all opposition to slackwater navigation ceased when a record flood sent water down the Monongahela destroying coal tipples and over one hundred barges on the Monongahela, but shippers within the Davis Island pool did not lose a single barge (Johnson 1985:105).

The Cincinnati and Louisville District engineers held public hearings in 1888 in response to a Congressionally authorized study for extending the six-foot minimum depth slackwater project down the Ohio. These hearings made it clear that the coal and navigation interests who had previously opposed canalization of the Ohio were now unanimously in favor of additional slackwater improvements (Johnson 1975: 169). Senator Matthew S. Quay (Repub.) of Beaver, Pennsylvania presented resolutions for improvements of the Ohio between Davis Island Dam and Raccoon Creek, Beaver County, Pennsylvania "in accordance with Col. W. E. Merrill, engineer in charge" (Congressional Record, Senate, 50th, 1st 1888). His colleague Thomas M. Bayne was also active in presenting resolutions from organizations like the "Commissioners for the Improvement of the Ohio River and its Tributaries", calling for improvements to the Ohio, Monongahela, Green, and Barren Rivers (Congressional Record, Senate, 50th, 1st 1888).

POLITICAL AND SOCIAL MATURITY IN OHIO RIVER VALLEY TOWNS

Strong political leadership was essential to a town's success. Business associations for urban advancement in Evansville, Henderson, Owensboro, and Paducah in the 1880s formed a cohesive political front that brought such firms as Ken-Rad, Bucyrus-Erie, Mead-Johnson, and Hercules to the Ohio Valley. Eventually, these associations became Chambers of Commerce (Bigham 1998:219).

Evansville's population doubled between 1870 and 1890, and doubled again by 1920. At that time, about 85,000 people lived within the city limits (Bigham 1988:15). Part of this growth came from the annexation of localities like Independence and Howell. Other factors included a higher birth rate and lower mortality rate, but this growth also came about as a chain reaction of events. Industrialization attracted new workers to the city eager to find employment in the new industries made possible by the steamboat packet trade on the river and the rail lines of the Evansville and Terre-Haute and the L&N (Bigham 1988:16). The increased influx of people created a population composed increasingly of wage-earners dependent on the industry of the urban areas, and less independent, having less control over their working conditions. In 1900, 14,000 residents worked in manufacturing, but by 1920, this figure had risen to 18,000. (Bigham 1988:17). Increased industrialization also led to increased consolidation of the factories. Layoffs and other threats to job security led to organized labor, as well as the more extreme Socialist Party of America led by Indiana's Eugene V. Debs (Bigham 1988:17).

Social distinctions developed rapidly in the West. These lines were economically based, and to a lesser extent professional. Societies for different groups sprang up in the first decades of the 1900s, and included such memberships as the St. Cecilia Society for ladies in Cincinnati, and the Quintillion Literary Society in Pittsburgh, as well as professional and charitable associations (Wade 1959:106). In Evansville, the Men's Business Association coined the name "Gateway to the South" for Evansville in the 1880s, showing their pride and hope for the possibilities that these transportation routes opened up (Bigham 1988:17).

Cities such as Cincinnati, Pittsburgh and Louisville early competed against each other for economic and political supremacy. The issue centered on control of river commerce, as the Ohio was the main commercial artery of the West (Wade 1959:327). Cincinnati and Louisville were major rival cities on the Ohio. Louisville had a geographic advantage being situated at the Falls of the Ohio, being a natural gateway to the South. Both cities fought for the favor of southern markets. When Cincinnati was chosen as the northern terminus of a proposed railroad to connect Charleston, South Carolina, Louisville demanded a branch line in exchange for a franchise to cross the state of Kentucky, as well as other concessions from Cincinnati, ultimately dooming the project (Ambler 1931:232).

The fight between Wheeling and Pittsburgh over the construction of the Wheeling Suspension Bridge illustrates just how fierce this competition could be - it took a local bridge building dispute, and propelled it into a national issue. Although Pittsburgh had a distinct commercial advantage geographically, the aspirations of Wheeling to become the chief commercial city of the upper Ohio, and the imminent completion of the B&O railroad to Wheeling caused Pittsburgh's opposition to grow. Pittsburghers fought the construction of the Wheeling bridge from the start, claiming that it was an obstruction to navigation, as it required large steamboats to lower their stacks to pass under the bridge. In June of 1849, a large group of Pittsburgh rivermen met to appeal to Supreme Court Judge Robert C. Grier, to grant an injunction against the construction of the bridge, but the first cable had already been positioned. The Commonwealth of Pennsylvania,

representing Pittsburgh, then sued the bridge company (Ambler 1931:220; Kemp & Fluty 1999). Although Wheeling lost in court, they succeeded in having Congress declare the bridge a post-road in 1852, and thus, the bridge could not be ordered down (Ambler 1931:227).

For many years, there were no general laws or provisions regarding bridges, but in 1870, Congress allowed for the creation of a board of engineers specifically for the examination of bridges crossing the Ohio River to report whether they were an impediment to free navigation of the river (Holt 1923:42). The group most interested in the maintenance of free navigation of the Ohio was the Pittsburgh coal shippers. Other interests, local and sectional, were more concerned about railroads and railroad bridges across the river. In the 1870s, the only major proponents of free navigation of the river in the state of Ohio were at Cincinnati. As a result, many railroads constructed bridges that impeded navigation of the Ohio either by obstructions of height, or by piers that caused shippers to break up coal fleets to pass. Coal producers still managed to ship the majority of their product by river (Ambler 1931:311-312). It wasn't until 1884 that Congress gave the Corps the authority to regulate the construction of bridges, and put upon the party constructing any bridge to pay the costs necessary to ensure that it did not interfere with free navigation (Holt 1923:42).

At the end of the 19th century, the states along the Ohio River exhibited wide variations of social and economic sophistication. Kentucky's economy was relatively stagnant due to poor rural roads, limited railroad construction, predominantly agrarian values, and generally poor education standards. Illinois, by contrast rapidly became an industrial and urbanized state. More than half of its population resided in urban areas, and the state's economy largely depended on iron and steel, as well as coal. Public education expanded greatly, and in 1914, the state developed a highway plan.

Indiana experienced advancement in its northern and central regions, but less so in the south. Ohio was perhaps the most dependent on river trade at this time. Evansville, in particular remained a leader in the commerce of the Ohio River, although a fair number of railroads crossed the state (Bigham 1998:198-200). Other towns, such as Cairo, continued to lack strong political leadership and this town, despite its unique position at the intersection of the Ohio and Mississippi Rivers, as well as a terminus for many railroads, declined. Cairo always had the threat of flooding, but that too, was partly due to the lack of solidarity of opinion among leadership and the lack of will to act decisively to protect the town from such floods. Cairo, which struggled throughout the early 19th century, had only about 200 residents in 1850. When the Illinois Central railroad line was completed to Cairo in 1855, the town grew, having a population of 2,188 by 1860. The town continued, however to be plagued with the threat of floods (Bigham 1988:103).

Darrel Bigham examined the development of the Lower Ohio Valley from settlement through about 1930 as an effort, in part, to discover why so many towns and cities experienced decline beginning in the 1880s. He studied why some remained stagnant, and yet others, especially Evansville, Indiana, Ownesboro Kentucky, and West Point grew remarkably. Cairo's example proved that an ideal location was no guarantee. He concluded that nothing was inevitable about the growth of these communities, but that a mixture of location, resources, market economy, political culture, leadership, and luck determined their future. He specifically pointed out that the decisions made in state and national legislatures made a difference (Bigham 1998:251-253). Evansville had expanded rail service by the late 1800s, and it served much of the expanding industry. Local businessman David J. Mackey gained control of local railroads, including the Paducah, Decatur and Evansville Railroad, but the panic of 1893 left Mackey bankrupt, and most of the railroads consolidated under external control and ownership.

The growing coalition of interests favoring Ohio River navigation improvements did not mean that the coal, navigation, and manufacturing interests agreed on the nature and location of these improvements. In July of 1888, Senator Matthew S. Quay submitted a resolution adopted by the Pittsburgh Coal Exchange strongly in favor of navigation improvements on the Ohio, but just as strongly disapproved of the current Congressional legislation calling for the construction of the next lock and dam to be at Beaver Pennsylvania, instead asking for construction of a lock and dam just below Davis Island. They were, in effect stating that proper navigation of the Ohio River required four locks and dams between Davis Island and Beaver, and not one (Congressional Record, Senate, 50th, 1st 1888).

PROGRESSIVE ERA POLITICS AND NAVIGATION IMPROVEMENTS

The Progressive Movement had a major impact on the course of Ohio River navigation development. Characteristics of the movement included concern for the protection of the country's natural wealth in forests, minerals and river systems with a dominant theme on the careful use of these resources to insure that the economy would have a lasting supply of raw materials. Advocates looked to scientific and professional cooperation with large corporations to develop a coherent policy of government regulation. Others were more interested in the chance to revive a mythical agrarian society and reverse the urban and industrial trend of society. Regulatory agencies like the Interstate Commerce Commission and the Federal Trade Commission were some of the vehicles through which reformers hoped to effect these scientific changes (Gould 1974:4).

The Republican party dominated the political arena during the Progressive Era. The Democrats' reign effectively ended with the economic depression of the early 1890s. Although the Republicans advocated "Big Business", the party was careful to advocate government action that would promote economic growth, and the economic recovery of the early-20th century gave the party its strength (Gould 1974:5). Although the Republicans were dominant, the Socialist movement expanded during this period, with Indiana's Eugene V. Debs as its chief advocate and candidate (Bigham 1988:17).

The social movements of this time propagated a renewed interest in slackwater improvements on the Ohio and waterways development in general. One contemporary writer stated: "The present movement (for inland waterways) is regarded as a great awakening to the need of national economy, and the conservation as well as the development of our natural resources . . . while there may be now and then a lull in the storm, the waterways movement is nevertheless firmly rooted, and will command attention for years to come" (Moulton 1912:3-4). In 1895, Cleveland held an International Waterways Convention. In 1901, the first National Rivers and Harbors Congress met in Baltimore. In 1903, New York appropriated $101,000,000 for the improvement of the Erie Canal. In 1906 the Rivers and Harbors Congress held conventions in both St. Louis and Washington, and on March 14 1907, President Theodore Roosevelt appointed the Inland Waterways Commission (Moulton 1912:1-2).

Hays' theory that the Progressive Movement was largely a professional movement, propelled to the forefront of national debate by scientists and other experts explains much of the link between conservation and river navigation improvements. Hays does not do justice to the social aspects of the movement. Massive changes in production modes, brought about by industrialization, economic distress, visible changes to the environment, loss of individual worker autonomy, and other factors all played a role in the coming of the Progressive Era. What is unique to the period is that America sought scientific solutions from experts to combat society's ills. The period following the Civil War exhibited greater social and political awareness of the American public. Social injustices in the workplace, including child labor and long work weeks of over sixty hours were frequent complaints. Labor unions began to assert their power, and business, as well as government, which appeared too often on the side of business, fought back. The depression of the 1890s, beginning with the panic of 1893, dramatized the social problems of the day. Citizens groups rallied against poor public facilities, tax favoritism, corruption in government, and business privileges. Growing concern about business consolidation and "trustification" gave way to fears of diminishing opportunity for the individual entrepreneur.

By 1900, these concerns had begun to take the form of a political agenda that stressed the fear of business consolidation and a call for government regulation of corporations. During the 1890s, large-scale businesses had multiplied. Railroads and steel industries in particular had become large consolidated "trusts" (Gould 1974:1-2).

Although work on rivers and harbors increased each year between 1881 and 1901 including during the Spanish American War, commerce on the Ohio was dying. In both Cincinnati and Louisville, statistics of commerce on river and rail showed how bad it was. In almost every category, cotton, tobacco, whisky, lard, corn, wheat, potatoes, flour, ham and bacon, the railroads carried from 95 to 99-percent of all commerce. The only significant exceptions were coffee and sugar, for which the Ohio carried twelve and seven-percent respectively (Hunter 1949:602). This was the beginning of a long-term trend. The total percentage of decline in tonnage between the years 1870 through 1910 totaled over 75-percent for the Ohio River (Hunter 1949:637).

The Interstate Commerce Act of 1887 proved a disappointment to Ohio River interests. River men had high hopes that the Interstate Commerce Commission (ICC) would alleviate the problems of steamboat men by enforcing a clause in the Act that forbade the railroads to make a greater charge for short haul than long haul freight. Since railroads could not lower their rates across the board to levels in effect at river points, the river men believed that the water carriers would be able to obtain higher rates and eventually eliminate the competition of the railroads at river terminals. In a blow to all river men, the ICC declared that the long and short haul clause was only applicable "under substantially similar circumstances and condition," meaning that because water competition was so dissimilar to rail service, that rate differences were justified (Hunter 1949:593). River interests were further disappointed by the Commission's decision that the clause in the Interstate Commerce Act of 1887 that compelled the railroads to enter into joint arrangements with water carriers for through shipments at through rates was not mandatory, but optional. As late as 1910, the Commissioner of Corporations noted that on the Ohio there was still no coordination of rail and river facilities at any river terminal (Hunter 1949:597-599).

In the latter half of the 19th century, the Grange Movement continued to play an important part in Ohio River political battles. Although most of these so-called granger laws were repealed or drastically modified within a few years the U.S. Supreme Court upheld some, and they served as the basis for much later legislation in the field of railroad and public-utility regulation.

During the 1890s, the rise of agrarian protest hurt both major parties, but infighting proved most divisive among the Democrats; their collapse at the polls followed in 1896. Beginning in that year, increased voter strength made the Republicans the majority party in the country for a generation. Party factionalism continued. Beginning in the 1890s a group of Republicans known as the Progressives sought to balance the party's commitment to the industrial elite with the use of federal power to correct some of the worst excesses of the monopolies and trusts that dominated the economy.

Although Congress began to fund additional improvements after the success of the Davis Island Dam, appropriations were slow. It was not until 1890 that Congress made appropriations for the second lock and dam improvement, the Merrill Dam. In that year, Congressman Thomas J. Henderson (Repub.) of Princeton Illinois, introduced H.R. 9486 for the "construction, repair, and preservation of . . . rivers and harbors . . ." (Congressional Record, House, 52nd 1st 1890). The issues in the debate included those opposed to the general "pork barrel" tendencies of the river and harbor appropriations that gave money for what they felt were "improvements to creeks." Congressmen made the bill the butt of jokes and derided the waste of public money. Issues such

as these, combined with a general complacency among Congressmen, some sections continued to create a difficult, but not wholly unfruitful environment for appropriations.

During the early 1890s, Congressmen such as Senator David Turpie (Dem.), Arthur H. Taylor (Dem.) of Petersburg Indiana continued to submit petitions for Ohio River improvement from chambers of commerce and citizens groups, as well as sponsoring legislation for navigation improvements. During the 53rd Congress, Arthur Taylor was appointed to the Committee on Rivers and Harbors. Taylor, along with John Dalzell (Repub.) of Pittsburgh, and Bellamy Storer (Repub.) of Cincinnati in the House, and John Sherman of Mansfield, Ohio in the Senate, continued to submit petitions from chambers of commerce. They also sponsored bills and amendments for rivers and harbors in general. Local commercial and citizens groups became more powerful and prolific in their agitation for improvements during the 1890s. Typical was the petitions for "artificial freshet navigation" on the Ohio River from the Pittsburgh Chamber of Commerce, introduced by John Dalzell in the House and a similar petition by the Cincinnati Chamber of Commerce submitted by John Sherman in the Senate in 1894 (Congressional Record, House and Senate, 53rd, 2nd 1894).

Other special interest groups were organized and exerted influence, including the Mahoning Valley Industrial Council, the American Waterways Operators Inc., the Wabash Valley Improvement Association, and the Propeller Clubs of the United States. In response to the lack of enthusiasm in Congress, in 1895, local interests formed the Ohio Valley Improvement Association (OVIA) at Cincinnati to campaign for canalization of the river (New York Times October 29, 1961 Section 11, p.4). In 1896, OVIA took the House Rivers and Harbors Committee on a tour of the Upper Ohio to emphasize the need for river improvements. (Johnson 1975: 169).

President Grover Cleveland vetoed the river and harbor bill of May 1896. He explained that the appropriations of the bill were instigated by private interests and promoted "local or individual profits" and therefore "could not fail to stimulate vicious paternalism and encourage a sentiment among our people already too prevalent, that their attachment to our Government may properly rest upon the hope and expectation of direct and special favors . . " (Congressional Record, Appendix 56th 2nd House 1901).

In 1898, Mr. Theodore Burton (Repub.)[Plate 2-8], Chairman of the Committee on Rivers and Harbors introduced an amendment to the 1898 River and Harbor bill for a survey to report on the cost and feasibility of constructing a lock and dam at "Cullums Riffle" near Cincinnati. He pointed out that the survey had already been completed by Major Bixby and it would only require a small expenditure to produce the report. Jacob H. Bromwell, (Repub.) member of the House from Cincinnati, also endorsed the survey (Congressional Record, House, 55th 2nd 1898). Under the urging of Senators Joseph Foraker (R) of Cincinnati and James McMillan (R), the Senate passed the amendment the next day (Congressional Record, Senate, 52nd 1st 1898). McMillan, although he had been a purchasing agent for the Detroit & Milwaukee Railroad and held positions for the Michigan Car Company, and acted as president of the Duluth, South Shore & Atlantic Railroad, saw that there was a great deal of benefit to cooperating with waterway transportation, and he held a great interest in shipbuilding and lake transportation companies as well (Moore 1915). During the next session, in February of 1899, the Secretary of War transmitted the report to the Committee on Rivers and Harbors ." (Congressional Record, House, 53rd 1st 1899). Congress appropriated the first funds for Locks and Dams Nos. 13 and 18 for the ports of Wheeling and Marietta in 1899 (Johnson 1975:169).

The turn of the century saw some monumental shifts in the political arena with the sudden rise of Theodore Roosevelt (Plate 2-9) to the presidency upon the assassination of William McKinley in 1901. Roosevelt, in addition to being an ardent promoter of the conservation movement, had the popular reputation as the enemy of the monied "trusts". Previous to the presidency, he had rubbed shoulders with muckrakers like Jacob Riis. Although Roosevelt targeted these industrial monopolies, he was not concerned with breaking up the monopolies so much as with correcting their evils. Some of the legislation that resulted from this fervor was the creation in 1903 of the Department of Commerce and Labor and a Bureau of Corporations. They were authorized to investigate business combinations and to warn against practices harmful to the public.

In 1901 the Northern Pacific, the Great Northern, and the Burlington railroad systems were brought together under the Northern Securities Company. In 1903, through Attorney General Philander C. Knox, Roosevelt brought suit under the Sherman Anti-Trust Act of 1890 for the dissolution of the Northern Securities Company as a conspiracy in restraint of trade. The United States won the suit. Suits were also begun against the United States Steel Corporation, the Standard Oil Company, and other large combinations. In all, Roosevelt obtained 25 indictments during his two administrations, although some of the cases were not decided until he was out of office.

In addition to dissolving the Northern Securities Company, Roosevelt attacked railroad monopoly in two acts passed by Congress. The Elkins Act made illegal the granting or accepting of secret rebates; that is, repayment of shipping charges. The Hepburn Act gave the Interstate Commerce Commission the right to fix rates. It extended the commission's jurisdiction to include pipelines, terminals, ferries, and express companies. It forbade railroads to grant free passes to anyone but employees, and it forbade the railroads to carry commodities in the production of which they had an interest.

The 56th Congress labored over the River and Harbor bill for 1901 at great length. In the House, those in favor of the bill included Jacob Ruppert Jr. (Dem.) of New York, who supported all the appropriations made under the bill, but predictably stressed that the improvement of the New York Harbor was of greater commercial importance than most of the projects, although he suggested that more was needed for the Mississippi. Nicholas Muller (Dem.) of Staten Island was less verbose, but just as strong in his approval for improvements to improvements to channels surrounding Staten Island, New York. David E. Finley (Dem.) of South Carolina also unequivocally endorsed the bill (H.R. 13189). James R. Mann (Repub.) of Illinois suggested that those who opposed the bill were unfamiliar with waterways and could not understand the complex interrelationship of trade and waterways improvements (Congressional Record, Appendix, 56th[d] 2nd 1901).

Republicans generally favored the bill, and Democrats, especially those from regions where waterways appropriations would be of little use, vilified it. William King (Dem.) of Utah opposed all the appropriations because to him it represented the epitome of pork, where each member of Congress felt obligated to "struggle for a portion of (the) booty" or face the wrath of their constituents. He opposed the deals that caused Congressmen from areas with worthy improvement projects to support unworthy projects to secure passage of the bill, saying that "to improve 'navigable' streams, millions of dollars are squandered on unnavigable ones." He also complained about private corporations that used their capital stock to subscribe a lobby to Congress and use previous bad precedents set by Congress as justifications for more appropriations. Along partisan lines, he stated "In my humble opinion, it is indefensible for any Democrat, even though he can succeed, to attempt to use the Treasury of the United States to aid in improvements that are personal or local. When Republicans are looting the Treasury and

Plate 2-8. Senator Theodore Burton

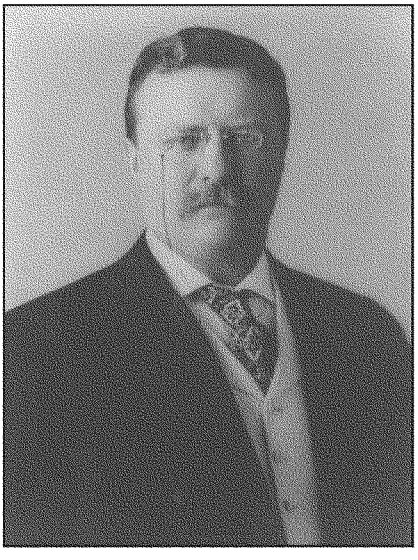

Plate 2-9. Theodore Roosevelt

seeking to employ the Government to benefit the few, the duty is, if possible, stronger than ever for the Democrats to defend the people and the Constitution and keep their hands clean. . . . Civil and political liberty are threatened by the Republican party, and industrial liberty is being destroyed by the power of wealth. Centralized power and aggregated wealth! These are the foes Democracy must challenge" (Congressional Record, Appendix, 56th[d] 2[nd] 1901).

By the time the bill reached the Senate, the majority had agreed to support it, and a conference had found disagreement on only four amendments, however, a minority continued to present formidable opposition. Thomas H. Carter (R) of Helena, Montana, with previous careers in agriculture and railroading, entered into a long filibuster against the bill. His intentions to oppose the bill were directly related to the killing of a shipping bill, also known as the subsidy bill, that intended to re-establish the Merchant Marine system. Opposition to this bill centered around the idea that it was meant to subsidize the freight costs of Standard Oil, the Pennsylvania Railroad, and other large "trusts". This bill, which he supported, passed the House but died in committee. He made it clear that he would do his best to defeat the river and harbor bill just like those who through "repeated speeches . . . deprived the majority in this Chamber from casting their votes in favor of the measure for which the majority stood" (Roeder 1989:23-29; Congressional Record, 56[d] 2[nd] 1901).

Carter argued that nine-tenths of the projects in the river and harbor bill for 1901 had no merit, and that the "rivers are not increasing in number; the harbors are not increasing; but Mr. President, we are starting out to make rivers where rivers do not exist." Carter saw the bill as a fraudulent attempt to extort money from the treasury for local, unconstitutional projects on creeks and swamps. He detailed projects in the bill that were easy to pick on, such as the harbor at Porcupine Island, Maine, and the Oak Orchard Creek work in New York, but steered clear of projects of more obvious merit such as the Mississippi and the Ohio. In Maryland, he noted that "every river, great and small . . . is remembered in this grab bag" (Congressional Record,, 56[d] 2[nd] 1901). Improvements to navigation of rivers, including to the Mississippi and Ohio, became difficult to justify when seen in the context of river usage. Although the Ohio River Canalization project continued to be constructed, albeit slowly, during the first decades of the 20[th] century, waterborne commerce on the Ohio River was dead. Steamboat packet service dwindled rapidly, and coal shipments had virtually ceased. The sudden end of the coal trade on the river came about due to the formation of the Monongahela River Consolidated Coal and Coke Company - a company that had been formed from over 100 small coal operators on the Monongahela. The "Combine", as it was sometimes called, made the decision to stop the coal trade on the Ohio in 1916, due to competition from Alabama coalfields and Oklahoma oil in the New Orleans market, as well as an increased local market for coal for the steel industry, eliminating the need to ship coal down river (Johnson 1975:179).

The decreased tonnage on the river had grave political implications, as it provided heavy ammunition for those who opposed river improvements. Calculations, even those estimates provided by the Districts indicated that railroad transportation was cheaper per ton-mile. The Corps countered with arguments that the project, once completed, would prove profitable. Major Malcolm Elliott, former Assistant Engineer in the Louisville District, for example, compared the Ohio River Canalization Project to a railroad under construction, stating that it could not be a profitable venture until completed (Johnson 1975:180-181).

Congressmen found themselves walking a thin line between losing their share of the money and inviting ridicule for supporting useless projects. Many became more selective in their support. Benjamin R. Tillman (Dem.) of Trenton, South Carolina, for instance, was mixed in his support for navigation projects. Previous to his career in Congress, he had been a farmer, and Governor

of South Carolina from 1890 to 1894. Tillman argued that projects on his own state's Oconee and Ocmulgee rivers were not objectionable, but that he had little respect for the attempts of other Senators and Representatives seeking surveys of their areas under the guise of improving navigation when all they hoped to achieve was the possibility of lowering railroad freight rates through competition (Simpkins 1967). Tillman objected to the Mississippi improvements saying that "the Mississippi itself has quit having any steamboats on it . . . and the whole scheme of river improvement is a humbug and a steal, but if you are going to steal, let us divide it out and do not go to complaining." (Congressional Record, 56^{d} 2nd 1901).

Thomas Carter challenged that the improvements had not created a regulation of freight rates or improved trade, proof of which could be seen in the perishing of the towns along the Mississippi River which, with few exceptions, constituted "a standing contradiction to that statement" (Congressional Record, 56^{d} 2nd 1901). In mockery, Carter often called the projects "Swamp navigation" (Congressional Record, 56^{d} 2nd 1901). Carter was curiously silent on the topic of the Ohio River improvements.

Steel and other manufacturing interests on the river continued to be at the mercy of the railroads for shipping their freight. Although cities like Wheeling had lost some of their industries, others grew. Wheeling, once a great nail producing center, had lost this industry, but Pittsburgh had become a great steel producer. The *Pittsburgh Chronicle* decried the "rapid development of the railroads that had destroyed the river commerce." The paper stated that the rivers were "still the most attractive means of transportation, citing the many thousands of pleasure boaters who crowded packets for Cincinnati, Morgantown, Charleston, and other river towns." This paper awaited the completion of work that had begun with the Davis Island Dam, and expected that soon the river would be navigable year round (*Pittsburgh Chronicle Telegraph* September 18, 1908).

After the drawn out controversy of 1901, the next few years of the 20th century brought little argument in Congress concerning navigation improvements. Legislators lacked enthusiasm to support navigation improvements, and the decrease in traffic on the Ohio and other river systems seemed to justify ending further expenditures rather than increasing them.

At the turn of the century, there were three major issues creating obstacles to continuation of Ohio River slackwater improvements: Should the improvements be continued to the Lower Ohio River; was there adequate benefits to justify the cost of increasing the pool depths to nine feet; and was the canalization project justifiable considering the decline of commerce on inland rivers. After 1902, due to accusations of "pork" Congress appropriated little money on the Ohio River or its tributaries. Generally Congress only approved funds for maintenance and operation, provided the projects assisted commercial traffic. Engineers desperate not to see the baby thrown out with the bathwater urged that it was the political system that was at fault, and not the Corps of Engineers or Congress. Many recommended that instead of a piecemeal system of appropriations instituted by Congressmen, that each project be reviewed and approved by the Corps of Engineers before Congress could appropriate funds. As a result, in 1902, the Corps created the Board of Engineers for Rivers and Harbors to review all projects, presumably independent of local politics. (Johnson 1975: 171). The "Lockwood Board," named after its senior member, Colonel Daniel W. Lockwood, grappled with these issues. All of the members of this commission were Ohio River District Engineers.

There were many factors that attributed to the decline in river traffic, including railroad competition and charges collected at city wharves, but the Board found that the chief cause of decline was the "unreliability" of the navigation of the river in its unimproved state (Johnson

1975: 170). Major William L. Sibert, recommended raising the first six dams to provide a nine-foot channel, since six foot was insufficient for modern barge towing. In 1906, the Lockwood Board recommended the construction of a nine-foot project from Pittsburgh to Cairo. There were many who did not agree with this recommendation, including the editors of *Engineering News*, who doubted that the project could ever pay for itself in increased river traffic. Congress approved the nine-foot depth for the first six dams in 1905 (Johnson 1975: 169, 172).

One could follow the public debate over river improvements in engineering journal articles and books written by professionals. Dr. Emory Johnson, professor of Transportation and Commerce at the University of Pennsylvania, author of several books on railway and waterway transportation, wrote a book in 1906 on inland waterway transportation, in which he promoted the completion of the Ohio River navigation slackwater system to a channel depth of nine feet as quickly as possible due to the importance of the great industrial interests in the region (Johnson 1906:381).

In Congress, representatives James Hughes (Dem.) of Huntington, West Virginia, Stephen Morgan (Repub.) of Oak Hill, Ohio, James Kehoe (Repub.) of Maysville, Kentucky, and Swager Sherley (Dem.) of Louisville all introduced bills for construction of locks and dams on the Ohio during 1903 and 1904, but little debate ensued. The same was true in 1905, when Sherley and J. B. Bennett (Repub.) of Greenup, Kentucky introduced bills for the construction of locks and dams again. There seems to have been a beginning of a coalition of interests among Congressmen from several regions beginning at this time. As legislators struggled to garner support for their projects, they found support with other regions looking for a piece of the pie. In 1905, James R. Mann (Repub.) of Chicago Illinois supported river and harbor bills with more fervor, not only for his area, but across the board. William Adamson (Dem.) of Georgia became active in the debate as well, but these new alignments were in their infancy (Congressional Record, House and Senate, 57th & 59th 1902-1905). In 1906, the Kentucky State Legislature memorialized Congress, asking that it adopt "a broad and liberal policy toward the waterways of our nation", rather than intermittent and inadequate appropriations (Congressional Record, Senate, 59th, 1st 1906).

J. McGee, founding member and one-time president of the National Geographic Society, has been credited with playing a major role in outlining the philosophy that became the Conservation Movement. In 1903, McGee, along with Senator Joseph Ransdell supported the Lakes to Gulf Deep Waterway. The Corps, charged with examining the feasibility of the waterway, initially discredited the entire project, but by 1907, had been pressed by Congress and others enough to state that the portion from Illinois to the Mississippi River may be feasible, but that the portion from Cairo to the Gulf was not. Theodore Burton, chairman of the Rivers and Harbors Committee supported the Corps' recommendation. Sentiment in the Mississippi Valley, however, was against the Corps. Frank Smith, in his book, *The Politics of Conservation*, suggests that McGee then came up with the idea of an Inland Waterways Commission (IWC) to bypass Burton and the Corps, whom Smith suggests was simply protecting itself (Smith 1966: 105). In the IWC, McGee suggested a multidisciplinary approach to conservation that required cooperation between the Army Corps, Forest Service, Reclamation Service, the USGS, and other agencies. McGee, either somewhat naïve to politics, assumed that these diverse agencies could cooperate without rivalry and dissent, or he expected that the Corps, having only one vote on the Rivers and Harbors Committee, would not be powerful enough to thwart his purposes.

Following in large part the recommendations of McGee, in 1907, Theodore Roosevelt created the Inland Waterways Commission. Composed of two Senators, two Representatives, the Chief of Engineers, the Chief of the Forestry Service, the Chief of the Reclamation Service, the Chief of

the Bureau of Corporations, and a representative from the Bureau of Soils, the Commission recommended sweeping changes in waterways policies. McGee obtained an appointment to the Bureau of Soils to make himself eligible to serve as chairman of the new commission. The IWC's findings stated: "Hereafter, plans for the improvement of navigation in inland waterways . . . should take account of the purification of water, the development of power, the control of floods, the reclamation of lands by irrigation and drainage, and all other uses of the waters or benefits to be derived from their control" (Smith 1966: 107-108).

Regarding the Ohio River, the IWC reported that the railroads hindered the development of river traffic by gaining control of much of the land available for landing and terminal facilities as well as occupying long stretches of land along the banks with tracks, making the river inaccessible to navigation. The Commission's report noted that railroad control of terminal facilities and their withdrawal from prorating arrangements with the river lines created serious problems. Other impediments to river commerce included wharfage charges at terminals largely owned by municipalities that often approached 25-percent of the carrier's profit. All the members of the Commission agreed with one exception: Chief of Engineers, general Alexander MacKenzie did not endorse these recommendations. McKenzie saw government involvement in hydroelectric power production, flood control, and anything else not directly related to navigation, as unconstitutional (Hays 1959:104-105; Inland Waterways Commission Report 1908:109). The final IWC report includes his letter of dissent. The 1907 Newlands Bill, introduced by Senator Francis G. Newlands (Plate 2-10), sought to implement the proposals of the IWC, but the combination of unwillingness in Congress to spend more public money, opposition from the Corps, and longtime opponents to waterways in general, defeated the measure repeatedly. Despite having the strong backing of Theodore Roosevelt, the bill died as a result of Corps opposition, and Taft's sympathy for the Corps as the Secretary of War (Smith 1966: 108).

During the 59th Congressional session of the winter 1906 to 1907, Ohio Valley legislators in both House and Senate actively garnered support. In the House, Augustus Stanley (D) of Henderson, Kentucky (and Governor of Kentucky from 1915-1919) supported a dredging and snag removal bill, while the Senate authorized work on locks and dams 9, 10, and 12 of the Ohio based upon the endorsement of the Corps of Engineers. Nathan B. Scott (Repub.) of Wheeling, West Virginia introduced this bill as S. 88 in the Senate (Congressional Record, House & Senate, 59th, 2nd 1907).

Writers continued to take up the subject of waterway commerce. One such author, Herbert Quick, published *American Inland Waterways* in 1909. The book's subtitle, *Their Relation to Railway Transportation and to the National Welfare; Their Creation, Restoration and Maintenance,* sheds light on the author's purpose. He explains at the start that "The country is humming with agitation for waterways . . . chiefly, I think, it comes from the collapse of the railways under the tremendous traffic of our last three years of flush times" (Quick 1909:29). Quick found that the railways were killing waterway commerce in an unfair manner (as many of his day had decided), and "having found the way by which the railways may be prevented from killing water-borne traffic, we must make our waterways fit for their work" (Quick 1909:V).

Quick advocated Theodore Roosevelt's connection of conservation to waterway navigation improvement, as well as Roosevelt's penchant for fighting the monopolistic tendencies of the railroads, but cautioned that waterways should only be promoted if they were economically feasible. As could be expected, Quick also promoted the recommendations of the original Inland Waterways Commission. His book elevated Senator Theodore Burton, Senator Francis Newlands, General Mackenzie of the Army, and Gifford Pinchot whom he called "one of the most potent men for good now living" (Quick 1909:131). He promoted the ideas of Chief

Plate 2-10. Senator Francis Newlands

Hydrographer for the U.S. Geological Survey, Marshall O. Leighton who studied flood control reservoirs for the Inland Waterways Commission. William Bixby and Leighton agreed that flood control reservoirs should be part of the greater system along the Ohio and other rivers, but Bixby did not think federal law provided for flood control, but strictly navigation (Johnson 1975:193).

Republican Senators and Representatives began to take advantage of the growing conservation and progressive movements that were gaining momentum under President Theodore Roosevelt to promote river navigation. The Progressive Era brought intense criticism of the "pork barrel" system of politics that favored local improvements based upon political power at the expense of nationally expedient planning. Therefore, supporters of conservation and river and harbors improvements found it expedient to merge. During the 60th Congress in the winter of 1907-1908, the issues of forest and water conservation merged with navigation interests in several bills. Supporters of waterways improvements gained momentum by linking the popular conservation movement, the relation of waterways to the reclamation of flooded lands, the development of water power, increased sanitation, the supposed cheapness of water transportation, and the monopolistic tendencies of the railroads in their attempts to gain Congressional support (Moulton 1912:447). All interests benefited from this linking of causes. There was no shame in such linkages, since, according to many scientific experts, preservation of forests prevented silting of rivers, thereby decreasing the cost of flood damage and needs for dredging. It appeared the most economical way to preserve mountain forests and the navigability of the rivers.

Some Congressmen supported the river and harbors bill of the 60th Congress because it promised to alleviate flooding. Democrat Edward Saunders of Virginia supported the proposition, saying that the recent flood at Pittsburgh left all wondering if science knew the cause and the solution, to which he replied: "science and experience are agreed on the causes, and the remedy. The most potent cause is deforestation, the remedy for which is reforestation." William Reeder (R) of Logan, Kansas cited a circular that concluded that all engineers agreed: "The fact is . . . there is absolutely no difference of opinion among scientific men" that deforestation was the cause of silting and flooding (Congressional Record, House, 60th, 1st 1908). Reeder, originally from Cumberland County Pennsylvania, had personal interests in irrigation and farming, and supported the Progressive Republican move to link resource conservation and navigation.

In a move strikingly similar to Henry Clay's provision in 1812 giving states the ability to share appropriations for internal improvements on their borders, Charles F. Scott (R) of Iola, Kansas introduced bill H.R. 21986 "to enable any State to cooperate with any other State or States, or with the United States for the conservation of the navigability of navigable rivers, and to provide for the appointment of a commission . . ." (Congressional Record, House, 60th, 1st 1908). Scott was chairman of the Committee on Agriculture from March 1901 until March 1911. This bill provided for the Secretary of Agriculture (where the Forest Service was lodged), to advise and determine the connection of forestry works with navigation, and to create a National Forest Commission. Scott, and most other legislators, felt that this connection to navigation necessary, since the Committee on Agriculture did not think that the United States could constitutionally purchase lands for creating forest reservations, unless specifically linked to navigation. (Congressional Record, House & Senate, 60th, 1st 1908).

Waterways engineers were often their own worst enemies when it came to garnering political support for Ohio River improvements. Experts would publicly disagree over runoff calculations, methods of flood control, the best lock and dam technology, and countless other issues. There was also a major rivalry between civil and military engineers, and between members of committees and commissions (such as the Inland Waterways Commission), and engineers who resented the members, who often knew nothing about engineering, making decisions on the best

methods to improve navigation. An example of such a controversy, Marshall Leighton published an article in *Engineering News* of May 7, 1908 on the topic of reservoirs for flood control and navigation. Captain W. D. Connor of the U.S. Corps of Army engineers dismissed his ideas as impractical and based upon false assumptions, contended that Leighton's cost estimates were way off base, and made other more technical arguments against Leighton's proposal as well. Many of the arguments pitted Army engineers against civilian engineers as well. These highly public forms of professional disagreement left many Congressmen confused, and although some simply used the arguments that best suited their purpose, others, wishing to get at the truth of the issues, found no comfort in such differences of opinion (Quick 1909:190-194).

The Governors' Conference on the Conservation of Natural Resources, organized by Gifford Pinchot (Plate 2-11) and held on May 13-15 of 1909 at the White House, propelled conservation issues into the forefront of public consciousness. The governors held a second Conference at the end of the year to receive the recommendations of the National Conservation Commission. The National Conservation Commission, appointed in June by Theodore Roosevelt and composed of representatives of Congress and relevant executive agencies with Gifford Pinchot as chairman, compiled an inventory of U.S. natural resources and presented Pinchot's concepts of resource management as a comprehensive policy recommendation in a three-volume report. Commonly known as the Gannett Report, the Commission submitted it to Congress at the beginning of 1909.

1908-1909 PARTY PLATFORMS

Both the Democratic and Republican party platforms of 1908 pledged support to the development of navigable waters and conservation of natural resources under a comprehensive plan. Roosevelt chose William Howard Taft (Plate 2-12) as his successor, and the Republican party named him as presidential candidate in the election of 1908, in which he defeated William Jennings Bryan. Taft, a Cincinnati lawyer, became nationally prominent as a figure in Republican politics in 1890 when President Benjamin Harrison chose him as U.S. Solicitor General. In 1904 his friend President Theodore Roosevelt appointed Taft Secretary of War. Taft became a close adviser to the President and was prominent in Latin American affairs, conducting the delicate negotiations attending U.S. intervention in Cuba in 1906. Roosevelt expected Taft to continue his policies, and to a large extent he did. He vigorously prosecuted the Trusts under the Sherman Anti Trust Act; the Mann-Elkins Act of 1910 strengthened the Interstate Commerce Commission; and Taft's Latin American policy, known as "dollar diplomacy," was to an extent only an enlargement of Roosevelt's Panama policy and the Roosevelt Corollary to the Monroe Doctrine.

Members of the Republican party who favored Progressive policies became increasingly restive, and this Insurgent movement grew strong. Taft grew at odds with the Progressive elements in his party: he failed to support the Insurgents' attempt to oust speaker of the House, Joseph Cannon (R) and he favored the Payne-Aldrich Tariff, a high-tariff measure that was denounced by Progressive Republicans. The Senate altered the House's moderate Payne Bill so as to increase rates on manufactured goods, thus favoring the industrial Northeast and angering Midwestern Progressives. Taft also supported Richard Ballinger against Gifford Pinchot in the Ballinger-Pinchot controversy.

Pinchot was a rising star in the Roosevelt Administration and Progressive Party in the first decade of the 20th century. After Congress authorized the National Forest Commission in 1896, he served as a commissioner, and then from 1898 to 1910 as chief of the Division of Forestry (now the Forest Service) of the U.S. Department of Agriculture. During that period Pinchot filed charges against Richard Achilles Ballinger, then Secretary of the Interior, accusing him of abandoning the nation's conservation policies in his administration of coal lands in Alaska. President William Howard Taft supported Ballinger, and in 1910 dismissed Pinchot for insubordination.

The second Congressional session of the 61st Congress in 1910 attracted a great deal of debate focused on the Ohio Valley. Both the Democratic and Republican party platforms included a commitment to the development comprehensive planning and development of waterways in conjunction with natural resource conservation. The Republicans stated that they had inaugurated the reform of waterways and conservation with the impetus of Theodore Roosevelt. The Democrats specifically stated that the development of rivers should be combined with conservation, irrigation, drainage of swamp lands, and the utilization of water power.

The political climate that had previously necessitated a convergence of interests, seemed less important in 1910. In the Senate, Theodore Burton (R) of Illinois had just finished his 13-year service on the Committee on Rivers and Harbors. He had also been appointed by President Theodore Roosevelt as chairman of the Inland Waterways Commission in 1907-1908. He became chairman of the National Waterways Commission from 1908 until 1912. Burton reflected the frustration of Ohio Valley interests but was more particular about what he endorsed in the river and harbor bill, arguing that only those items that had a favorable report from the

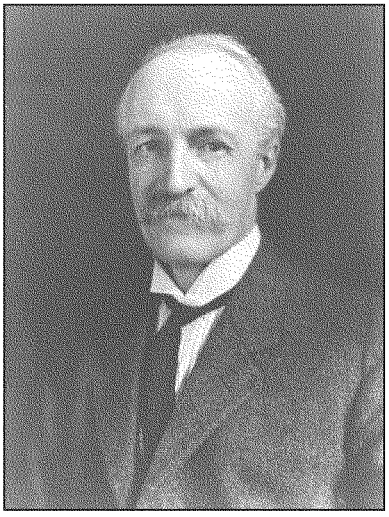

Plate 2-11. Gifford Pinchot

Plate 2-12. President William Howard Taft

Corps of Engineers should receive the greatest attention. Burton argued that the worst offense of the latest bills was the failure to "finish the great trunk lines" and as a result, tributaries had been finished, yet the main lines prevented these lines from being profitably used. "The Ohio is a great artery of commerce. Improvements have been made costing tens of millions of dollars for branch streams like the Big Sandy . . . . As a result there is a more uniform and at times a greater depth of water in the Big Sandy and the Green rivers than in the Ohio River where those rivers empty into it" (Congressional Record, Senate, 61st 2nd 1910). Any previous alliances he had with Congressmen of neighboring states were clearly foreclosed by his interest in gaining a lions share for the Ohio. He argued with Thomas Paynter (D) of Frankfort, Kentucky against completing Lock 14 on the Kentucky River, calling it a waste of government money. He advocated railroad transportation as a viable alternative to less important waterways, and stressed that instead of the piecemeal appropriations for the Ohio, Congress should approve larger sums in order to finish the work.

Burton, who previously had little objection to the argument of using waterway development to regulate railroad rates, now argued that it was an inefficient way to regulate freight rates. Burton now relied heavily upon organizations more in line with his interests, such as the Lakes to the Gulf Deep Waterway Association, which advocated deep water navigation improvements for the Mississippi and Ohio Rivers. Asked to rank the most important waterways of the nation, Burton replied: One . . . is the barge canal from Buffalo to the Hudson River, and down that river to New York. . . . The next, I would say . . . would be the Ohio River, from Pittsburgh down to Cairo. Why? Because there are great stores of coal and there is a busy, industrial country below it on the Ohio which is a great consumer of coal, of the mineral products, and of the finished iron and steel coming from Pittsburgh Then, again, there is a great deal of clay for brick along portions of the Ohio" (Congressional Record, Senate, 61st 2nd 1910).

Burton, along with Newlands of Nevada argued that from 1902 through 1909, Congress funded no projects without the recommendation of the Board of Engineers, but that the current bill departed from this practice. They advocated the policy of only appropriating funds for projects endorsed by the Board, and that any projects not so endorsed were likely scientifically and economically unwise. When confronted with the fact that despite expenditures in recent years, river traffic had declined steadily, they argued that one could not expect increases in tonnage until the entire work was completed, likening it to a half-finished railroad " (Congressional Record, Senate, 61st 2nd 1910).

Burton's speech on April 16, 1910 on the varying merits of waterways projects brought heated opposition from Senators William Warner (R) and William Stone (D) of Missouri, William Lorimer (Repub.) of Chicago Illinois, Frank Brandegee (Repub.) of Connecticut, and others. Burton also opposed the linking of conservation issues with navigation, as he saw it as a useless drain on funds that should be directly applied to completing the Ohio navigation system. He pursued a filibuster on June 24, 1910. Among his arguments, he contested the idea that all experts agreed that conservation helped navigation by quoting Brigadier-General William H. Bixby, Chief of Engineers, who supposedly stated that "he would not spend 5 per cent of (money for navigation) for any such purpose as is contemplated in this bill." Burton, who continued at length against the bill, bristled at the accusation of "filibuster" from other Senators, saying that the issue was too important to pass without careful consideration. Burton, a moderate Republican accused the muckrakers in journalism of indiscriminately attacking their Congressmen for not supporting large expenditures for public projects for the "uplifting" of the poorer classes (Congressional Record, Senate, 61st 2nd 1910).

The Lockwood Board had recommended the construction of a nine-foot waterway from Pittsburgh to Cairo. In 1905, Congress bought into the idea and Taft, a Cincinnati native, supported it. In 1910, Congress authorized the project for the entire length of the Ohio (Johnson 1975: 173). President Taft, although he made it clear that he strongly disagreed with the system of making numerous small appropriations rather than complete the most useful projects, signed the bill.

Progressive reformers generally believed that the railroads monopolized transportation of the country, charging extortionist rates. They pointed out that wherever railroads competed with waterways, railroad rates were substantially lower. Proponents of waterways argued that the Government should aid in waterway development to alleviate this unfair situation. President Taft, in a message to Congress on January 14, 1910, stated that "it is certain that the existence of such methods of traffic materially affects the rates which the railroads charge, and it is the best regulator of those rates that we have, not even excepting the governmental regulation through the Interstate Commerce Commission" (Moulton 1912:13-14). Speaking as the President of the National Rivers and Harbors Congress, Representative Joseph E. Ransdell (Dem.) stated: "I am convinced that waterway transportation in this country, under favorable conditions, costs about one sixth as much as the average cost by rail" (Moulton 1912:12).

In 1912, Harold Moulton, instructor in political economy at the University of Chicago, published *Waterways Versus Railways*, in which he attempted to present the arguments and facts for and against waterways improvements. He favored the railroads, but presented a remarkably unbiased analysis, admitting that the railroads were monopolies that had an unfair advantage due to the fact that almost all the boats on the Great Lakes and the Ohio River were either owned outright, or controlled by the railroad through majority stock ownership (Moulton 1912:28-29). This was a common accusation at the time. In areas where the railroads did not control waterways, he asserted that railroads adjusted rates near waterways to cause the traffic to prefer to use the railroads. He summarized the argument of the waterways block: "The knowledge that the railways have adopted such methods as these to defeat the waterways has raised a storm of protest, and developed the contention that, if the waterways were afforded protection from such crushing competition, they would speedily regain their former position in the transportation of the country" (Moulton 1912:84-85).

As was common in his time, Moulton reported in great detail the success of the waterways of Europe and the great extent to which these countries used waterways profitably. These he compared to the waterways extant in the United States, concluding that their success was based upon unique situations and history, and did not prove or disprove that all waterway projects in the United States could be profitable. He did decide, that in fact many proposed waterways, such as the proposed Chicago River and Drainage Canal - from Chicago to St. Louis, were not practical. Interestingly, despite his book's tendency to increasingly unfold his bias towards railroads, Moulton, asserted that the Ohio River was unique, as it alone had "retained a large traffic in recent years" (Moulton 1912:392).

Moulton stated that the recent approval in 1910 of a plan to improve the Ohio River, extending its depth to nine feet was practical and would be profitable since the Ohio had a number of industrial towns, that carried on trade with the Pittsburgh region, and had an excellent position in relation to trade routes. Especially important, he stated was the iron and steel industries in the region. Mouton makes extensive reference to the Ohio Valley Improvement Association and the efforts of the Governor to promote the project (Moulton 1912:394).

Concluding with support for the railroads, Moulton wrote that the evidence pointed strongly against the feasibility of most water transportation in the Unites States. In his view, the railroads had the clear advantage of not being tied to a valley or pre-determined route, but could go anywhere. He asserted that motives other than public service motivated the "second waterways movement." These motives, he asserted were a variety of private construction companies who hoped to receive contracts in return for political support, politicians who had financial interests related to waterway construction, and business interests who hoped to lower their shipping costs at the cost of the public purse. He specifically mentions the Ohio Valley Improvement Association which, in 1908 showed an expenditure of $11,232.79. They obviously hoped for a return on this investment (Moulton 1912:450).

THE POLITICS OF FLOOD CONTROL AND OHIO RIVER NAVIGATION

With the support of President Theodore Roosevelt and the creation of the Inland Waterways Commission, the issue of government aid for flood control received greater scrutiny. Congressional support, however was still weak. The 1911 report of the National Waterways Commission voiced a popular opinion that the "Federal Government has no constitutional authority to engage in works intended primarily for flood prevention or power development. Its activities are limited to the control and promotion of navigation and works incident thereto. The commission is one of the opinion that flood prevention is primarily a local problem " (Johnson 1975:193).

By 1912, Taft's relations with Roosevelt had deteriorated, and the former President joined the opposition. In 1912, Roosevelt fought vigorously for the Republican presidential nomination. When he failed and Taft got the nomination, Roosevelt ran in the election as the Progressive (popularly called Bull Moose) candidate. All three parties, Democrat, Republican, and Progressive, made a commitment to a comprehensive conservation policy including flood control, resource conservation, and waterway navigation. Recent devastating floods along the Mississippi and Ohio strengthened the weight of these issues. The Republican vote split between Republicans and Progressives, however, and the Democratic candidate, Woodrow Wilson, won.

As in the past, it took a disaster to effect changes, since in the throes of an emergency, a change in flood policy would have fewer political repercussions. The flood of 1913, popularly known as the "Dayton Flood", rose one foot above the 1884 flood, causing extensive damage in the Ohio River Basin. Damages at Louisville alone were estimated at a half a million dollars and 361 people had died in the disaster. Congress immediately organized the Miami Conservancy District to plan and construct flood control project for the Miami River basin. This results of this action created a pioneer flood control project, and more importantly, had great influence on future Congressional support for flood control projects when it proved effective in preventing damage far in excess of its cost (Johnson 1975:193-196). While the Miami Conservancy District was planning flood control works, the Secretary of War directed the Chief of Engineers to appoint a Board of Engineers to investigate methods for preventing flood damage through the construction of navigation improvement projects. The Ohio River Flood Board made a preliminary report in 1914, but opposed the linking of flood control to navigation improvements, stating that the issue should be addressed based on the benefits to the protection of life and property that would result. Congress was not prepared to take this leap (Johnson 1975:199).

Senator Francis Newlands, who had been promoting a bill for the regulation of navigable rivers through various means including reservoirs (Newlands-Bartholdt river regulation bill), saw the floods of 1912 and 1913 as a chance to re-submit his bill. Herbert Quick, in *American Inland Waterways,* argued in favor of the 1909 version of this bill which provided for a permanent Inland Waterways Commission vested with power for funding and coordinating waterways projects (Quick 1909:177).

Newlands, best known for what is known as the Newlands Reclamation Act of 1902 was a land speculator from Mississippi, who moved to Nevada. He recognized the need to build a reservoir to expand agricultural production within his holdings and personally hired his own engineers to determine where would be the best place to put a dam. He also ran for the U.S. Senate. Newlands won election and set out to convince Congress that the nation needed these dams. Rather than just limit the language to the State of Nevada, he ensured the wording of the legislation would allow the building of dams throughout the West. Newlands promoted the bill as

a comprehensive planning approach to the combined issues of flood control, conservation, and navigation. Much to the disappointment of State elected officials, and some speculate only as a result of the assassination of President McKinley in 1902, the Reclamation Act came into being. (Congressional Record, Senate, 61st 2nd 1913).

THE DEMISE OF THE PROGRESSIVE PARTY COALITIONS

There was little opposition to river and harbor improvements in 1913. Between the demise of the Progressive party and World War I, the alliances between various regions of the country that had been effective in garnering support for navigation improvements deteriorated. Despite a promise to support the conservation initiative, a new era of political debate concerning river improvements came as hostilities in Europe approached, and some Republicans, in a break with the dying Progressive Party, found less reason to support navigation improvements.

Other representatives found reason to support navigation improvements based upon the need for adequate river transportation in war time. Representatives proposed bills for the survey and selection of a site for a naval armor plant in the Ohio Valley. William B. Francis (Dem.) of Martins Ferry, Ohio hoped to locate it in the Steubenville Manufacturing District near Lock and Dam number 10 on the Ohio, whereas Howard Sutherland (Repub.) of Elkins, West Virginia hoped to locate it in the Parkersburg Manufacturing District of West Virginia. Sutherland, having been engaged in the coal, timber, and railroad businesses had personal as well as political reasons to support the site (Casdorph 1974:1-25). Matthew M. Neely (Dem.) of West Virginia advocated yet another site in his district near Moundsville in Marshall County, West Virginia. Of course, the construction of such a plant was certain to decrease opposition to improvements on the Ohio. (Congressional Record, House, 63rd 2nd 1913).

Renewed protest against the river and harbor bill erupted in 1914. With a Democratic majority in power, Republicans used the river and harbor issue as a rallying cry against the Democrats. Led by James Frear of Wisconsin, Republicans generally opposed the river and harbor bill of 1914 as a sign of the wastefulness of the Democratic regime. Frear, as in previous sessions, championed himself as the enemy of "pork" and strongly opposed all river and harbor appropriations. 1914 also brought a bill to increase taxes for war preparations. Republicans linked this tax to the excesses in the river and harbor bill, and Frear reasoned that spending existing unspent money and defeating the new river and harbor appropriation would make a "war tax in time of peace" unnecessary. Frear's Republican colleagues, Frederick Britten (Repub.) of Chicago, Illinois, and Franklin Mondell (Repub.) of Wyoming, lamented that the Democratic majority would likely pass the bill even though it was, in their eyes, extravagant. Mondell, a businessman with interests in mining, railway construction, and coal and oil property development, may have had personal reasons for opposing appropriations, as well as coming from a region with strong isolationist tendencies. Democrat John Charles Linthicum of Maryland, on the other hand, challenged the Republicans to point out which items they considered "pork" (Congressional Record, Appendix, 64th 1st 1914).

Charles Lieb of Indiana promoted continued appropriations for the unfinished 9-foot Ohio River system. He likened the Ohio to the Panama Canal in importance, and reasoned that industrial growth would follow the completion of the project. He read letters of petition from a variety of industries in Evansville promoting completion of the work (Congressional Record, House, 64th, 1st 1914). In his remarks, he presented a letter from Samuel L. May, president of the National Contract Company of Evansville, contracted to construct Dam No. 10 at Steubenville, Ohio. May explained that he would most likely have to lay off 206 employees and lose an investment of over $150,000 if new appropriations did not come through Congress to complete the work. The Senate struck down the original House bill for $53,000,000, and passed a substitute measure for $20,000,000 (Congressional Record, Appendix, 64th, 1st 1914).

The experience of 1914 brought caution to the 1915 appropriation debates, as well as an increased competition for limited funds. The cooperation that had existed in times of large appropriations continued to break down. Stephen Sparkman (Dem.) of Florida supported the 1915 bill. He objected to the Congressmen from the Ohio, Mississippi, and Missouri River valleys suggesting that the appropriations for any but these three rivers constituted unnecessary "pork". In response, he stated that those three rivers alone took up half of all the proposed appropriations, suggesting that it would be much easier to fund a good many projects with the sacrifice of these three (Congressional Record, House, 64th, 1 1915).

In 1915, Senator George Oliver (Repub.) of Pittsburgh submitted an amendment to the River and Harbor bill to give the Chief of Engineers the option of constructing one lock and fixed dam on the Ohio River to replace Locks and Dams Nos. 1 and 2 if studies proved this to be desirable. Duncan Fletcher (Dem.) of Florida strenuously objected. He had previously been reminded that Congress agreed to avoid new expenditures in the bill for 1915. The disagreement between Oliver and Fletcher created discord in the chamber. Debate during this session nearly became violent as Senators Theodore Burton, James Reed (Dem.), Knute Nelson (Repub.) and William Kenyon (Repub.) of Ohio fought for diminishing funds. Theodore Burton, who had previously supported most river and harbor projects while on the Committee on Rivers and Harbors, became highly selective, opposing those that he felt were not reasonable, and especially those projects outside of the Ohio Valley. In 1915 he threatened to obstruct the bill indefinitely if Congress did not remove appropriation amendments for the Missouri and other rivers (Congressional Record, Senate 63rd 2nd 1915).

Despite the rivalries, the majority of Congressmen seemed to accept the notion that among river improvement projects, the Ohio, Mississippi, and perhaps the Missouri rivers were truly worthy of appropriations as national projects. Representative Thaddeus Caraway (Dem.) of Arkansas summed up this generally accepted viewpoint: "In passing I wish to say appropriations for the Mississippi and Ohio Rivers are not discussed in these remarks, because the Ohio River is cared for . . . and the Mississippi has been declared to be a national project by the platforms of both the great parties" (Congressional Record, House 63rd 2nd 1915).

In the House, men such as William Gordon (Dem.) of Ohio (Owner of Gordon Lumber of Cleveland, Ohio) tried to use rational arguments, but political arguments went beyond the rational or even the tendency to secure a portion for their portion of the river and harbor expenditures. Western Representatives like Nicholas Sinnot (Repub.) of Oregon were annoyed with those mid-western associates who had killed the "Apple Box" bill (H.R. 11178). Majority Leader Oscar Underwood (Dem.) of Alabama, (who grew up in Louisville, Kentucky) kept this bill from coming up for a vote. As the bill was vital to the apple industry of the West and Northwest, Sinnot made it clear that he would oppose the river and harbor appropriation bill in return (Congressional Record, House 63rd 2nd 1915). The River and Harbor bill for 1915 contained no new projects. Starting out at $50,000,000, it shrank to $25,000,000.

Most agreed that river traffic continued to decrease, but Robert Switzer (Repub.) of Gallipolis, Ohio disagreed with figures presented by the opposition producing figures from the Board of Engineers that showed an increase of 2,000,000 to 4,000,000 tons of tonnage a year on the Ohio. (Congressional Record, House 63rd 2nd 1915). Others argued that value, and not tonnage was a better gauge of usefulness. Switzer reported that of the planned 53 locks and dams, 15 were complete, 18 were in process, and 20 not yet begun.

THE PATH TO WORLD WAR

Between 1905 and 1907, railroads experienced shortages of available cars for transport, causing crises among manufacturing and agricultural markets. Shortages again became acute during World War I. The inability of the railroads to expedite transportation needs demonstrated the importance of barge transport as an effective and necessary system for transporting freight. This prompted Congress to further regulate the railroads, and to continue to aid in the development of navigation of the Ohio.

Joseph H. Moore (Repub.) of Philadelphia, who had been a close ally of Theodore Roosevelt, revived the argument that waterway development could effectively compel railroads to charge reasonable rates. Concerning the current crisis of the railroads to meet increasing wartime demands, he stated: "If the railroad men are wise - and some of them in the East begin to realize it - rather than retard waterway development they will encourage it, because where they have been subjected to the congestion such as they have endured during the last few months, carrying the products of the West to the seaboard, they find that it is desirable to have relief, some auxiliary, such as Mr. James J. Hill - builder of the Great Northern Railway - who, back in 1907, indicated must be had if the railroads of the country are to give effective service." (Congressional Record, House 64th 2nd 1916).

Alben Barkley (Dem.) of Paducah and Simeon Fess (Repub.) of Yellow Springs, Ohio stressed that Congress had, in 1910, committed to finishing the Ohio navigation system by 1922, and Congress should not break a promise made to the people of the United States (Congressional Record, House 64th 2nd 1916). Representative Frear of Wisconsin spoke out against the 1916 river and harbor bill in his usual fashion. He pointed out that commerce on the Ohio continued to decrease. Frear took the tonnage predictions for future commerce on the Ohio as estimated by Chief of Engineers Kingman, and picked it apart in a mocking fashion, pointing out what he perceived as obvious overly optimistic numbers. Despite this skepticism, he conceded that if there was any worthy river project, the Ohio qualified (Congressional Record, House 64th 2nd 1916).

Cries of "pork" continued to reverberate with regard to the river and harbor bill of 1916. In 1916, the *Philadelphia Inquirer* stated "The 'pork barrel' known to Congress is an appropriation bill carrying immense sums in the aggregate, which sums are distributed among Congressional districts on the principle of 'you tickle me and I'll tickle you.' There are usually two barrels. One contains hunks of appropriation pork for rivers and harbors. The other contains pap for nice little congressmen who have influence enough to demand and receive all sorts of money for all sorts of public buildings in all sorts of towns of their districts." (as quoted in the Congressional Record, House 64th 2nd 1916).

In 1916, Senator Paul O. Husting (Dem.) was not willing to spend time picking at items in that year's bill to see what, if any merited funding. He openly stated that he opposed the bill altogether. His opinion was that the extravagance of "hit or miss" spending on river and harbor appropriations had gone on too long, and he would rather each project stood or fell on its own merit. After such an outspoken introduction, he discussed only three rivers, reasoning that if they were not worth spending money on, then it would stand to reason that none would be. These three rivers were the Mississippi, the Ohio, and the Missouri. He provided the chamber with figures that showed decreased tonnage on these rivers, and asked how Congress could justify continuing to spend money in such a case. (Congressional Record, Senate 64th 2nd 1916).

Generally, funding for the Ohio River navigation system experienced the same political and economic whims of the nation that all the other projects were, but in the case of the Ohio, Mississippi, and Missouri, even opponents of river improvements often agreed on the merit of these systems. Senator William Kenyon had a moderate approach, only attacking those elements that he felt had little merit, admitting that both parties had, as a rule equally opposed and supported the river and harbor bills, and that the disagreements were more regional or sectional than "political" He was clear that the "Ohio and Monongahela Rivers have proven more of a success commercially." He dismissed accusations that he was prejudiced against waterways because he had once been counsel for a railroad company (Congressional Record, Senate 64th 2nd 1916). In 1917, Ollie James (Dem.) of Marion, Kentucky addressed the Senate on the improvements of the Ohio. He dismissed Frear's accusation of "pork" because Frear opposed all waterways improvements, however, he lauded former Senator Theodore Burton as having sound opinions on river improvements. He cited Burton's statements that even though most waterways were unfit for navigation improvements, the Ohio was one of the few that had merit, while Frear called the Ohio "the most wasteful project of all" (Congressional Record, Senate 64th 2nd 1916).

Many, including James Frear, the enemy of all river and harbor improvements, and William Graham (Repub.) of Illinois, considered all omnibus legislation wrong because it bundled good legislation with bad, and forced people to vote for things that they were opposed to hoping to gain approval of other measures. Graham and Frear found it an "unconscionable wrong" to consider appropriations for "pork barrel" measures like rivers and harbors when the country was at the brink of war (Congressional Record, Appendix 65th 1st 1917).

For many years Frear had been the most outspoken opponent of omnibus river and harbor legislation. On March 3, 1917, he gave his final and most memorable speech against such legislation. The speech was, in large part an indictment against the Chief of Engineers and the Rivers and Harbors Congress. Frear began with of the Chief of Engineers. Frear questioned the ability of an Army engineer to make decisions regarding the economic feasibility of projects. "The Army engineer has been shown to be unfitted by lack of business training, environment, or experience from performing a service filled by experts in economics, waterways, and business management in other countries. His social and official life unfits him for such a responsibility" (Congressional Record, Appendix 65th 1st 1917).

First, he said, the Chief had ignored the law passed in 1916 that required a reexamination of the merit of all river and harbor projects. He accused the engineers of deliberately presenting Congress with inflated figures on river tonnage, and having unethical ties to the National Rivers and Harbors Congress. Frear specifically indicted former Chief Brig. Gen. William H. Bixby, and current Chief of Engineers Black.

Frear had spoken out against this lobby before, and had introduced resolutions to investigate this 'mutual bribery' lobby. He quoted from the secretary of the group, Captain J.F. Ellison: "We send Congressmen here to legislate for the Nation, theoretically, but actually to get all he can for us, and if he does not get our share, and then some, we do our best to replace him" (Congressional Record, Appendix 65th 1st 1917).

Frear was especially agitated with the appointments to the 1917 Advisory Commission on Waterways made by the Council of National Defense. They included Brig. Gen. William M. Black, Chief of Engineers, Captain J. F. Ellison of Cincinnati, former secretary of the National Waterways Congress, James E. Smith, president of the Mississippi Valley Waterway Association, Walter S. Dickey, president of the Kansas City Missouri River Navigation Company, and M. J. Sanders, president of the New Orleans Board of Trade. All of these men admittedly had expertise

in waterways, but also had interests, in Frear's estimation, that were in conflict with the execution of their duties on that committee (Congressional Record, Appendix 65th 1st 1917).

He also submitted evidence that the Dredge Owners Protective Organization, a powerful lobby, had "fraudulently and unlawfully secretly divided up Government contracts in the past," and asserted that "the Chief of Engineers is in supreme control and helps perpetuate the present indefensible "pork barrel" system." (Congressional Record, Appendix 65th 1st 1917).

The Transportation Crisis of World War I

The reality of war altered the character of debate on river and harbor improvements. During the first session of the 65th Congress in 1917, the majority of the House and Senate supported the river and harbor bill, justifying the bill as a "war measure," but an outspoken minority which now included Senator Lawrence Sherman (Repub.) of Springfield, Illinois continued to argue that due to the decline of commerce on the Ohio River, Congress should re-think the whole project. In that year, the Chief of Engineers recommended only emergency navigation projects or those that aided in national defense. In the House, John Small (Dem.) of Washington, North Carolina cited a memorandum from former representative Frederick C. Stevens (Repub.) of Minnesota. In this letter, Stevens alerted Congress to a severe railroad car shortage of 145,449 cars in May, which he said was a slight increase in a shortage experienced in April 1917. He reported that the shortages had been increasing since September 1916, and that Congress needed to take quick action on waterways improvements or face a crisis of national security.

Small also quoted Daniel Willard, chairman of the advisory commission for the Council of National Defense, who asserted that rail transportation had reached its capacity. Small reminded his colleagues that during the rail car shortage of 1907, railroad magnate James J. Hill had stated essentially the same thing, and argued for coordination of rail and water interests. Small also reminded Congress that Secretary of War Newton W. Baker had endorsed the bill as necessary for preparedness (Congressional Record, House 65th 1st 1917). The issue of car shortage, although its severity was debated, did exist, and upon discussion of food and fuel conservation during the war effort, Senator Atlee Pomerene of Ohio reported that the Committee on Interstate Commerce had found that the severe shortage of rail cars had caused an increase in the price of coal (Congressional Record, House 65th 1st 1917).

Federal subsidies in Paducah benefited the barge construction industry. Munitions and other war related contracts were let to Ohio River industries including Bucyrus in Evansville, which produced shells. This interest in navigation also benefited grain industries. The demand for flourspar in steel production stimulated growth of industry in Rosiclare and Tolu, Kentucky. In 1918, Tolu became the site of a federally funded hospital. Camp Young, established in 1903 in Hardin County near West Point, became the 100,000-acre Fort Knox (Bigham 1998:218). All of these federal undertakings stimulated population growth as well as economic expansion.

During World War I, military construction in the Ohio River Valley came under the control of the Cantonment Division of the Quartermaster Corps, later renamed the Construction Division for the duration of the war. General George Goethals was Acting Quartermaster General in 1917 (Johnson 1975:210). Two of the largest projects in the Ohio Valley included the construction of Camp (later Fort) Knox near Louisville, and Wright-Patterson Air Force Base near Dayton Ohio (Johnson 1975:210).

During the war, civil works construction in the Ohio Valley River Basin diminished in scope and pace. Guards protected all navigation structures to watch against sabotage. A crisis arose with

the increase in commercial shipments and the large movements of troops and military supply shipments that customarily had been transported by railroad. In 1917, the railroads proved utterly unprepared to handle the increased volume, whereas the inland waterways remained vastly underutilized (Johnson 1975:211).

As a result of the railroad congestion, in June of 1917, Congress commissioned a study of the feasibility of using the waterways to relieve the pressure. The study resulted in the first direct government owned water transportation facilities with the operation of barge lines on the New York State Barge Canal (Erie Canal), the Misissippi, and Warrior rivers. Government operation of such facilities continued after the war with the creation of the Inland Waterways Corporation (IWC) in 1924 (Armstrong et al. 1976: 46-47).

The shortage of rail transportation spurred a great renaissance in the shipyards on the Ohio River. Yards began a major construction effort to meet the increased demands for transportation, and the Corps actively aided in this expanded use of the waterways. In addition, the Corps put every possible idle vessel to use for the movement of freight (Johnson 1975:212). Many local businesses began to build boats, but most focused on the construction of barges. In 1918 alone, 245 barges constructed on the Ohio reached Pittsburgh (Ambler 1931:424). The Dravo Corporation exemplified the renaissance that took place in the shipbuilding industry as a result of the First World War. The company, originally organized as the Dravo Contracting Company in 1891, established a plant at Neville Island in 1906. During the war, the company, like several others in the area, built boats out of sheer necessity.

In 1918, with the United States in the thick of the war and the transportation problem having become more acute, Congress experienced less opposition to reasonable water transportation bills. John Small used the climate of cooperation to argue for water terminals on the river systems. Stressing the need on the Ohio River, he argued that although the project would give the people a 9-foot navigation channel, without terminals for the boats and barges the system would be useless. He reported that the Chief of Engineers expressed the opinion that not one suitable terminal existed on the whole river. The exigencies of war apparently altered Frear's response to waterway improvements. While he still objected to some items without merit, he admitted that "many real waterways need improvement, and several large harbor projects are needed for war purposes, so the bill is not opposed as a whole." Frear instead argued that harbors were fourteen times as valuable for commerce and war than rivers based upon a comparison of the appropriations to the ratios of expense and tonnage for the largest rivers, the Ohio, Mississippi and Missouri vs. the Superior-Duluth, Ashland, and Milwaukee harbors. He therefore found that the Ohio was an "extravagance" (Congressional Record, House 66th 1st 1918).

In reality, the Ohio River Canalization project greatly aided the war efforts by providing industries with low-cost, dependable transportation. "In the 1930s, the cost of moving non-metallic minerals on the Ohio was less than a third and steel products less than a quarter of the comparable rail rates" (Johnson 1975:227).

OHIO RIVER INDUSTRIAL GROWTH AFTER WORLD WAR I

Effects of the War on Ohio River Navigation

Ohio river commerce had declined steadily since the 1890s and work on locks and dams had virtually ceased. The statistics for the Annual Report of the Chief of Engineers for 1920 were disappointing, although a change in river use was imminent. The Chief of Engineers, no doubt feeling the pressure of Congress resulting from the discouragingly low amount of commerce on the Ohio River, stated that "The great benefit claimed for the improvement will be felt only when the slack-water system has been extended far enough downstream to permit continuous navigation at all times (except when interrupted by floods or ice) over a longer section of the river, connecting the large cities on the upper with those on the middle and lower sections. The commercial effect of the series of completed dams on the upper river is reflected in the marked increase in general traffic and in the amount of coal shipped from the mines along the Monongahela River to industrial plants on the Ohio River at Alquippa and Midland, Pa., and Steubenville Ohio. . . . This increased movement of freight is not shown in the commercial statistics, due to the fact that it occurred during the present calendar year, whereas the commercial statistics are for the calendar year 1919" (Report of the Chief of Engineers 1920: 1344-1345). General Lansing H. Beach, Chief of Engineers in 1920, pressed upon Congress the importance of improved waterways as was borne out by the recent war transportation shortage. Congress responded with the Transportation Act of 1920 (Johnson 1975:212).

In 1920, Representative John Small could finally report that large vessel use of the Ohio River had been on the rise, resulting in a "substantial increase in the amount of water-borne commerce" (Congressional Record, House 66th 2nd 1920). Locally, newspapers in the Ohio River Valley began promoting the navigation improvements with greater fervor as it neared completion. In February of 1923, the *Pittsburgh Sunday Post* headline read: "Ohio and Mississippi to Save the Nation Millions When, With Improvement Program Completed, Vast Fleets Ply From Pittsburgh to the Mexican Gulf". Despite the fact that most river industries now used river transport, rails, and roads to their advantage, opponents still made accusations of "Pork" and rivalries between the railroads and river interests continued. The paper urged that the river system would only be viable in cooperation with the railroads and road system and the benefit to the country would come from cooperation of these three distribution systems "freely and in the friendly spirit of co-operation". Still combating accusations of "Pork", the newspaper argued that "The practice of political powers passing out contracts to favored contractors is nowhere evident." (*Pittsburgh Post* February 11, 1923).

The Post noted that in 1921, the Jones and Laughlin Steel Corporation made an experimental shipment of 1,000 tons of steel and shipped it down the Ohio and Mississippi and thence inland by rail at a savings of $10,000 in freight, and had been using the system ever since. Although many doubted the efficacy of using the rivers, some foresaw the potential in using barges on the river. When, in 1921, the company made the experimental journey, the *Pittsburgh Sun* hailed Jones and Laughlin as a "pioneer in this revival of the rivers" (*Sun* December 10, 1921).

The Pittsburgh *Chronicle Telegraph* noted that the City of Pittsburgh was still not interested in river transportation judging by the neglect of river terminals in that city. Secretary of War Weeks noted in the Sixty-sixth Congress that Pittsburgh had 130 acres of undeveloped water front, and that while private businesses were constructing terminals on the river, the city had no terminals. Weeks stated that the "most crying need is water terminals equipped with modern machinery for quick and economical handling of freight in order that the large number of small shippers in

Pittsburgh may avail themselves of the cheaper river rates (*Chronicle-Telegraph* March 1, 1922)."

Indeed, the U.S. Steel Company used the river extensively and the Pittsburgh Steel Company had two steamers and 40 barges on the river. Wheeling Steel, Pittsburgh Steel, the American Bridge Company, National Tube Company, the American Steel and Wire Company, McClintic Marshall Company, the Tennessee Coal and Iron Company, Illinois Steel Company, the Inland Steel Company, and Crucible Steel began using the river system around this time as well (*Pittsburgh Post* February 11, 1923).

In 1923, the Jones and Laughlin Company had eight steamboats, 300 steel barges and 20 more under construction. The *Sun* noted that companies both large and small were erecting terminal facilities. The *Sun* reported: "One such terminal, being built by the Carnegie Steel Company on the Monongahela, will cost $500,000 while two others for the Jones & Laughlin Corporation at Pittsburgh and Woodlawn will cost $300,000. The terminal of the Wheeling Steel Corporation at Wheeling is to cost $200,000. The river craft has a freight displacement in the Pittsburgh District equivalent to 20,000 railroad cars" (*Sun* February 19, 1923)

The Jones and Laughlin Steel Corporation hosted dinners and supplied accommodations for delegates of OVIA during many of their meetings during the push to complete the canalization project. In 1928, they urged a timely completion of the project by 1929. Other local companies, including Carnegie Steel and Rogers Sand Company also hosted events for the delegates (*Post-Gazette* October 4 1928).

Some of the most active members of OVIA were community leaders of Evansville and Paducah who, because they understood the importance of river improvements, positioned themselves to most benefit from the work. They worked hard and methodically for these improvements. When the canalization was completed in 1929, few cities and towns realized the potential that it created.

Growth of Ohio River Industries and Towns After World War I

Some cities began to plan for the use of the new navigation system, but realization of its potential was slow. In 1930, the City of Pittsburgh planned the construction of one river-rail terminal on the Ohio in the Manchester District. The city had other terminals on the Monongahela, but most of the terminals continued to be privately owned facilities. In 1931, Ethel C. Leahy published *Who's Who on the Ohio River and its Tributaries*, which gave a snapshot of the towns and industries along the Ohio immediately after the slackwater navigation system was completed. Woodlawn, later consolidated with Alquippa, was home to the Jones and Laughlin Steel Corporation. Midland, in Beaver County, had as its principle industries the Midland Steel Co., Wheeling Steel Corp., and the Yellow Poplar Company. Portsmouth, Ohio had as its principal industries iron, steel and shoe manufacturing. Industries in Aberdeen, Ohio included D. A. Ellis Coal, Miami Coal, and Suiter Material Company. Higginsport, Ohio was a boat building center.

In Newport, Kentucky, there were the Hatfield-Campbell Creek Coal Company, the Ohio River Sand and Gravel Company, and Andrews Steel Mills. Cincinnati had "over 300 diversified industries" including the Cincinnati Sheet Metal and Roofing Company, the American Barge Line, many sand and gravel companies, a city owned railroad (Cincinnati Southern). The city boasted its position as the origin of the Ohio Valley Improvement Association in 1895, and host of the recent National Rivers and Harbors Congress.

The town of Madison, Indiana had diverse industries including saw mills and Howard's Marine Ways. Jeffersonville, Indiana boasted the American Car and Foundry and Howard's Shipyards and Marine Repair Plant. Louisville, Kentucky had iron, steel, hardware, printing, pipe, casket, wagon, baseball bat, and other factories. It also had a new terminal operated by the American Barge Line. New Albany, Indiana became a boat building and manufacturing center. Evansville housed many industries, including sand and gravel companies, the Mead Johnson River and Rail Terminal, newly opened in 1931, and others. Paducah had among its interests the Ayer and Lord Tie Company shipbuilding operations, Arrow Transportation Company, and the West Kentucky Coal Company.

Mound City had marine ways of the Mound City Ship Yard and Dock Company, which boasted having built gunboats during the Civil War. Wellsville, Ohio had the American Sheet and Tin Plate Company, Mingo Junction, Ohio had Mingo Steel Works (Carnegie), Wheeling was home to Wheeling Steel, Mail Pouch Tobacco, Ohio River Sand and Gravel, Standard Oil, Pure Oil Company, and others. Benwood, West Virginia also had works of the Wheeling Steel Corporation. Sisterville, West Virginia, was a principal producer of oil and gasoline, and Clarington, Ohio had two boat-building industries. Marietta, Ohio boasted Remington-Rand, Inc., Marietta Chair Company, National Refining Co., U.S. Tool and Supply Company, and a number of smaller businesses. Point Pleasant, West Virginia had a B & O Railroad Yard, Enterprise Dock Company, and the Point Pleasant Machine Works. At Huntington, West Virginia stood several sand and gravel companies and coal companies, Ashland, Kentucky and Ironton, Ohio both had rolling mills, blast furnaces, foundries, machine shops, and other steel production industries. (Leahy 1931:517-540).

River tonnage, which had almost been non-existent in 1919, had increased to over 14,000,000 tons by 1932. By 1934, tonnage in the Cincinnati district had increased 23-percent over that of 1929. Before the U.S. entered World War II, tonnage had increased to a remarkable 29,600,000 tons in 1940. Most of this freight was in the form of coal, coke, iron and steel, with petroleum and cement products increasing as well. (*Waterways Journal* September 5, 1936; December 27, 1941). The number of major shipyards and barge builders on the Ohio continued to grow in response to the increased tonnage on the river, and the aftermath of World War I. Table 2-1 lists those active in 1931.

Table 2-1: Active Shipyards on the Ohio in 1931

American Bridge Company	Pittsburgh, Pennsylvania
American Steel Dredge Company	Fort Wayne, Indiana
Ayer and Lord Tie Company	Paducah, Kentucky
Cook Brothers and Thomas	Clarington, Ohio
Dravo Contracting Company	Nevile Island, Pittsburgh, Pennsylvania
Chas. Hegewald Company	New Albany, Indiana
Howard Shipyard & Dock Company	Jeffersonville, Indiana
Independent Bridge Company	Pittsburgh, Pennsylvania
Peter Jensen and Company	New Albany, Indiana
Jones & Laughlin Steel Company	Pittsburgh, Pennsylvania
Kanawha Dock Company	Point Pleasant, West Virginia
Marietta Manufacturing Company	Point Pleasant, West Virginia
Midland Barge Company	Midland, Pennsylvania
McClintic-Marshall Company	Pittsburgh, Pennsylvania
Madison Ways (Howards)	Madison, Indiana
Nashville, Bridge Company	Nashville, Tennessee
Mound City Shipyards & Ways	Mound City, Illinois
Riter-Conley Company	Pittsburgh, Pennsylvania
Riverside Mill Company	Antiquity, Ohio
Tennessee River Boatyards	Knoxville, Tennessee
Treadwell Construction Company	Midland, Pennsylvania
Ward Engineering Works	Charleston, West Virginia
Zier Boiler & Sheet Iron Company	New Albany, Indiana

Source: Leahy 1931

The *Waterways Journal,* politically active as well, urged subscribers to contact their Congressmen on bills such as the 1936 Short Haul Bill introduced by Representative Samuel B. Pettengill (D) of South Bend, Indiana. The bill allowed railroads to charge different rates for long and short haul freight, calling it a "complete turnover in public sentiment toward the railroad industry" (*Waterways Journal* March 28, 1936).

"308 REPORTS"

In 1925, Congress authorized the Corps and the Federal Power Commission to submit cost estimates for combined flood control, navigation, hydroelectric power generation and irrigation improvements for every major river in the Unites States. These reports, known as the "308 Reports" since they were printed in House Document No. 308 of the 68th Congress, 1st Session, were collectively the first public proposal for the concept of multiple-purpose water resource development by the Corps of Engineers (Johnson 1975:199).

The "308 Reports" recommended levees and reservoirs for flood control, but Congress still expected that local and state governments would have to finance and construct flood control projects. The Great Depression of the 1930s made this all but impossible (Johnson 1975:201).

DEPRESSION, FLOODS, AND RELIEF

Although the Corps completed the Ohio River slackwater navigation system before the market crash of 1929, the first decade after completion was one of dire hardship for many in the Ohio Valley as elsewhere. Thus the system had to prove its worth in a particularly difficult time.

The response to the Great Depression - FDR's New Deal - made the depression a fortuitous event for the Ohio River during the late 1930s. FDR's relief programs, specifically the Public Works Administration (PWA) and the Works Progress Administration (WPA), would not have existed but for the depression. These agencies completed scores of projects in some way related to river navigation.

During the disastrous floods of 1937, Governor Chandler of Kentucky had no trouble convincing WPA Chief Harry Hopkins to begin WPA emergency evacuation work along the Ohio River. George Goodman sent over twelve thousand WPA workers to flooded areas in forty counties, many of whom went to work constructing levees on the Ohio. In addition, CCC workers and NYA students helped with relief work along the river (Blakey 1986:193). Federal relief, however came with a price. It showed that the national government could better combat such natural emergencies and it promoted the shift from self-reliance and state autonomy to greater dependence on the Federal Government. Those who adapted to the new political realities reaped the rewards of this new era (Blakey 1986:194).

The Louisville District recommended that the best method of protection from floods would be to construct a series of reservoirs in the valley, but the state of Kentucky and local communities lacked any financial resources to effect such improvements. The "308 Report" for the Ohio River recommended a series of fourteen reservoirs for immediate construction. Impediments included lack of monies, but the reasons were deeper than mere lack of funds. Different local and state governments were reluctant, especially in such lean times, to finance projects that would benefit other regions, and most felt that since the benefits crossed jurisdictional lines, the federal government should construct these improvements with tax money from all those who would benefit (Johnson 1975:203).

As in the past, it took a disaster to weaken the political opposition to river improvements. The disastrous flood of 1936, which claimed about 200 lives and hundreds of millions of dollars of property, and the so called "Superflood" of 1937 removed all opposition to federal aid for flood control in the Ohio River Basin. Conditions were so bad that the City of Louisville declared martial law. Damage was estimated at over four hundred million dollars, and the War Department spent over ten million dollars for flood relief and emergency work to prevent further damage. The American Red Cross spent over seven million dollars (Johnson 1975:205).

Some argued that the slackwater system on the Ohio caused silting of the river and had been the cause of increased flooding. This became a serious threat to navigation interests as a grand jury in Louisville had, on February 26, called upon the federal government to make outright grants and not loans to the flood victims based upon its finding that the navigation dams on the Ohio river, and not the heavy winter rains, had been the cause of the flood. Therefore, the grand jury saddled the United States with responsibility for the flood. The U.S. Army engineers vigorously denied that the flooding was caused by their improvements. Cincinnati meteorologist and flood expert W.C. Devereaux termed the idea a "silly theory". And Captain Lucious D. Clay of the Army engineers officially declared that the dams had "no appreciable effect" on the flood (*Waterways Journal* March 6, 1937). The *Waterways Journal* responded unequivocally with

measurements taken by the Army that proved that the depth of the river at the location of the dams had not changed since their construction, and significant silting had not occurred (*Waterways Journal,* September 16 1939). President Franklin Roosevelt, Congressmen, local residents, civic groups, and even railroads urged that improvements for flood protection become integrated into Ohio River improvements (Johnson 1975:207).

Within 60 days of direction from the House Committee of Flood Control, the Corps completed their recommendations for the construction of levees, floodwalls, and channel improvements for the protection of 155 communities in the Ohio Basin, including the construction of 45 reservoirs on tributary streams. Under the pressure to take quick action, Congress approved the study with the appropriation for almost twenty-five million dollars for the commencement of the recommended projects with the Flood Control Act of August 28, 1937. With this, flood control became a major mission of the Corps of Engineers (Johnson 1975:208).

Passage of the Flood Control Act of 1937 did not automatically create a favorable atmosphere for flood control reservoirs. Local and state politics still put up road blocks. When the Louisville District made plans for a flood control reservoir and hydroelectric power system in the White River near Shoals, Indiana in 1945, the district encountered strong opposition from local residents. The Governors of Illinois and Indiana also opposed the project due to its enormous size since it would inundate areas that generated large tax revenues for the state and county governments (Johnson 1975:259).

The Board of Engineers for Rivers and Harbors and the Chief of Engineers agreed with the Governors to abandon plans for three reservoirs including the projects at Shoals, Spencer, and Wolf Creek, and to instead construct a single project known as the Cagles Mill Reservoir. The Corps completed the dam and lake on Mill Creek, a tributary of the Eel River in 1958. Serious opposition to the Wabash Basin projects evaporated when the recreational value became apparent, and in 1958, 1965, and 1968, Congress authorized additional projects for the Wabash Basin (Johnson 1975:262).

In other areas local opposition made Congressional approval difficult since local Congressmen were not likely to vote against their constituent's wishes. The Louisville District recommended seven reservoir projects for flood control in the Green River Basin, and an additional large reservoir above lock No. 3 on the Green River following the 1937 flood. Known as the Mining City Reservoir, many feared that it would inundate Mammoth Cave. Not surprisingly, residents who lived in the areas to be flooded strongly opposed the project.

WORLD WAR II

With the advent of the defense emergency in 1939, ton-mile traffic on the Ohio rose 14.6-percent during 1940, and in 1941 it rose over 37-percent. Commodities consisted of coal, iron and steel, petroleum, scrap metal, and sulfur (*Waterways Journal* December 13, 1941). The *Waterways Journal* reported that by December 1941, the Ohio river shipyards cooperated by accepting contracts for Army and Navy vessels for ocean service. The Marietta Manufacturing Company in Point Pleasant West Virginia delivered the first units: four U.S. Navy net tenders. These were the Gum Tree, Larch, Holly and Elder, each 1,100 horsepower diesels. This company then began work on an order of 12 steam mine planters for the Army. The Dravo Corporation at Neville Island Ways began work on 15 sub chasers. The Nashville Bridge Company began construction of two mine sweepers, and the Jeffersonville Boat and Machine Company began construction of four sub chasers (*Waterways Journal* December 27, 1941). This company began construction 16 mine planters (*Waterways Journal* November 1, 1941). Barges were also under construction by these companies for war purposes. The Nashville Bridge Company built five cargo barges for the Inland Waterways Corporation, and the Dravo Corporation had begun construction of five deck barges 41 cargo barges, and 21 oil barges. The Weirton Steel Company began an order for ten coal barges. The Marietta Manufacturing Company also constructed two oil barges and five hopper barges. The Nashville Bridge Company had started three acid barges for the Carbide and Carbon Chemicals Corporation and nine oil barges. The Jeffersonville Boat and Machine Company of Jeffersonville Indiana was building two oil barges and one towboat for the American Barge Line Company (*Waterways Journal* December 6, 1941).

After the attack on Pearl Harbor the Corps of Engineers took responsibility for rapid mobilization of national resources, and diverted efforts away from improvements to navigation and flood control. Projects included airfield construction, quarters and training facilities for troops, utilities, roads, fencing, and the erection of office buildings to name but a few. Civil works on the Ohio were virtually suspended between 1942 and 1945 with unfortunate consequences, as several floods, most notably the March 1945 flood produced severe damage, killed 24 people and shut down 188 war production plants while impeding progress on another 93 plants (Johnson 1975:255).

In 1940, Congress proposed a radical decrease in funds for rivers and harbors by nearly 50-percent in order to make way for increased defense funding. Congressman Dewey Short (Repub.) of Missouri, president of the National Rivers and Harbors Congress led the fight to restore the appropriations, and Major General Julian L. Schley, Chief of Army engineers also warned that these funds were necessary for the defense of the nation (National Rivers and Harbors News, January 1940).

In 1941, *Railway Age* noted that a resolution introduced by Senator Vandenberg of Michigan (R) to require the formal recommendation to the Congress by the Board of Engineers for Rivers and Harbors of any bill before it could be authorized would curb the distribution of "pork" (*Railway Age* January 18, 1941). The journal criticized the tactic of introducing river and harbor items as vital to "national defense" just to get them passed, as FDR had promised to veto anything that was not vital to national defense. The journal was even more critical of the Inland Waterways Corporation, which it called the "socialist transport venture" because it had reported a net loss of $273,725 in 1940. It mocked the assertions made by the government that despite the loss, the actual direct savings to the public was in the range of two million dollars (*Railway Age* January 18, 1941). Wartime construction contracts caused a shortage of experienced rivermen, and OVIA

and the Waterways Journal began to advertise the need for new pilots, engineers, and other personnel to operate these new vessels (*Waterways Journal* November 1, 1941).

An example of the impact of the war on the growth of industry on the Ohio can be seen in the full page advertisement taken by the Ashland Oil & Refining Company in the December 27 1941 issue of the *Waterways Journal.* It boasted that the company aided in the war effort by shipping over 1,000,000 tons of crude oil in 1941, and was expanding its fleet with an additional five towboats and 37 steel barges that would increase their capacity by 50,000 tons (*Waterways Journal* December 27, 1941).

In light of the impending defense needs, OVIA drew up a set of resolutions urging the federal government to renew its support for flood protection and transportation facilities in order that the Ohio Valley might do its utmost to support the war effort (*Waterways Journal* May 3, 1941). By 1942, the *Waterways Journal* announced that every shipyard from Pittsburgh to Cairo was working at capacity to launch river craft, and the fleet was still unable to handle the war tonnage being turned out (*Waterways Journal* February 14, 1942).

In early 1942, the Navy Department announced that it planned to construct a shipyard at Evansville for the assembly of large boats. It was located just west of the Mead Johnson river terminal and operated by the Missouri Valley Bridge and Iron Company based in Leavenworth Kansas. It became a major producer of tugs and specialized landing craft for military equipment for the war effort (*Waterways Journal* February 21, 1942). Transportation of oil on the Mississippi and Ohio by barge was considered much safer than by tanker during the war, as tankers were open to attack on the ocean. General Eugene Reybold, Chief of Engineers in 1942, pointed out that the nation had a great advantage of having a completed navigation system on the Ohio that was not available during the last great war (*New Orleans Times Picayune*, May 18, 1942). River authorities and public officials spoke at length at the 36th annual meeting of the National Rivers and Harbors Congress in 1942 on the topic of increased use of inland waterways to aid the war effort. The officials found "bottlenecks" obstructing the full use of waterways for the war effort. These included the lack of sufficient oil barges and towboats and the opposition of the railroads.

Just before the attack on Pearl Harbor, the Corps began a major expansion program at Fort Knox, and the number of structures at the post grew from 864 in 1939 to over 3,000 by 1942. During World War II, the fort held large numbers of troops.

The Ohio River became the conduit for transportation of great stores of munitions from newly constructed ordnance and munitions plants. In the Louisville District alone, these included the Ohio River Ordnance Works at Henderson, Kentucky, the Hoosier Ordnance and Indiana Ordnance plants at Charlestown, Indiana, the Evansville Ordnance Plant at Evansville Indiana, the Blue Grass Ordnance Depot at Richmond, Kentucky, the Fall Creek Ordnance Plant at Indianapolis, and the Vigo and Terre Haute Ordnance Plants (Johnson 1975:220-221). The Evansville plant was operated by the Chrysler Corporation. The Remington Corporation converted its Kings Mills plant in Cincinnati to a .45 caliber ammunition plant. Other private companies involved in arms production included the Sunbeam Electric Company, which produced cartridge cases in Evansville (Thomson & Mayo 1960: 202).

The Corps expanded river facilities at the Warner Gear Division of the Borg-Warner Corporation at Muncie, Indiana and the ordnance-testing facilities at Jefferson Proving Ground, Madison Indiana (Johnson 1975:221). Private corporations benefiting from these developments included the E.I. du Pont de Nemours Company which operated the Indiana and Hoosier Ordnance plants

at Charlestown Indiana for the production of smokeless powder and the Chrysler Corporation which owned the renovated Evansville Ordnance plant, a producer of .45 caliber ammunition.

The Ohio River canalization proved to be invaluable to the war effort. As during World War I, river navigation greatly reduced the pressure on the railroads which were nearly paralyzed by the volume of transportation needed. Barges on the river transported petroleum equivalent to seven million rail tanker carloads during the war, and permitted widespread geographic distribution of military products. During the war inland river shipyards produced 4,031 landing craft and small ships. The Ohio Valley shipyards produced about a thousand vessels, including 585 LSTs, (Landing Ship Tanks), a naval ship specially designed to transport and deploy troops, vehicles, and supplies onto foreign shores. In addition, the shipyards produced 74 LCTs (Landing Craft Tanks) used to get heavy tanks and vehicles ashore in a hurry, 47 tugs, 36 patrol cruisers, and 16 mine-layers. Most of these ships came from Evansville, Indiana shipyards and the American Bridge Company shipyards at Ambridge, Pennsylvania (Plate 2-13). These shipyards were crucial for the war effort, and without the navigation system, they would not have been a reality. Through Lend-Lease the United States provided 113 LSTs to Britain. The Ohio River Canalization project greatly aided the war efforts by providing industries with low-cost, dependable transportation. "In the 1930s, the cost of moving non-metallic minerals on the Ohio was less than a third and steel products less than a quarter of the comparable rail rates" (Johnson 1975:232).

"The improvement of the river channel at the turn of the century, had a synergistic effect. Evansville and Paducah became major shipbuilding centers during World War II." Fort Knox's expansion accelerated West Point's inclusion in metropolitan Louisville, and Camp Breckinridge, the training grounds for thousands of troops, both owed their location to a navigable river. The lock and dam system promoted acceleration in the abundant coal areas near Paducah, which in turn led to the construction of large aluminum-processing facilities near Hawesville, Henderson, and Newburgh. This growth, in turn created sufficient demand for river commerce to justify enlargement and modernization of the lock and dam system in the 1970s (Bigham 1998:251).

MID 20TH CENTURY

In 1950, engineers from Electric Energy Incorporated began inspecting sites in the Ohio Valley for construction of a multi-million dollar steam operated electric plant. The company's engineers rejected one of the potential sites in the Green River Valley due to the risk of floods and lack of adequate navigation facilities. This galvanized local leaders to organize the Green River Valley Citizens League, whose purpose was to promote economic development in the region. The League's first action was to endorse the construction of four flood control reservoirs in the valley. The members of this group represented the interests of the people living downstream of the proposed reservoirs and would benefit from the flood protection that the projects would afford. Opposition to the group was strongest among those whose homes would be flooded, or the "upstream" interests. This "upstream versus downstream" controversy was typical of nearly all the proposed flood control reservoir projects (Johnson 1975:262-263).

Disastrous floods continued to settle controversies over reservoir projects. A typical example of this was the Howardstown Lake project on the Salt River. Similarly, in the Kentucky River Basin, the "upstream-downstream" conflict was strong. Additionally, the project at Jessamine Creek attracted great opposition since it would inundate a large number of historic sites. Residents of Owsley County opposed the Boonville Lake project, being satisfied with the status quo, but others fought for the project because they expected that the reservoir would bring economic opportunity to a very poor area (Johnson 1975:264). Many of the reservoir projects would probably never have been approved if it had not been for flood disasters that swayed public and political support in favor of flood control programs. The shift from mere flood control to the concept of reservoir projects with a multipurpose program having numerous benefits also proved a major catalyst in changing public and political opinion. Public and political opposition decreased to reservoir projects as people recognized the advantages in terms of economic growth, recreation, flood control, and power generation.

The publication of Arthur Maass' book: *Muddy Waters: The Army Engineers and the Nation's Rivers* introduced a new era of criticism against the Army engineers. This work was especially significant because an early draft of his work was made available to the staff of the Hoover Commission Task Force on Natural Resources in 1948 and the President's Water Resources Policy Commission of 1950. It had a significant impact on the findings of these commissions. Maass contended that the Corps of Engineers wielded a dangerous level of control because direct relations between Congress and the Corps enable the Engineers to bypass the President. He explained that since members of Congress could not get approval for any particular project without a favorable report from the Corps, that the members tend to pressure the Corps for a favorable report, and the Engineers become directly responsible to individual members of Congress. All of this was accomplished in committee hearings, and thus, Maass argued, Congress and the Corps bypassed the President through legislation by committee resolution. He concurred with the notion that the individual project nature of the omnibus rivers and harbors bills constituted "pork barrel" legislation. He noted that this was not a rational national water policy, and that the waste came from the lack of a clear plan. Maass asserted that when the Hoover Commission, in 1949, set out to consolidate the functions of the Corps of Engineers and the Bureau of Reclamation into a Water Development and Use Service within the Department of Interior, the supporters of the Corps fought the bill, and Congress defeated it (Maass 1950).

Harold L. Ickes wrote the introduction to the *Muddy Waters*. In accepting the invitation from Maass to do so, Ickes wrote: The Corps of Army Eingineers [sic] has developed, in my judgement, into a positive administrative evil. It is a veritable old man of the sea, clinging to the

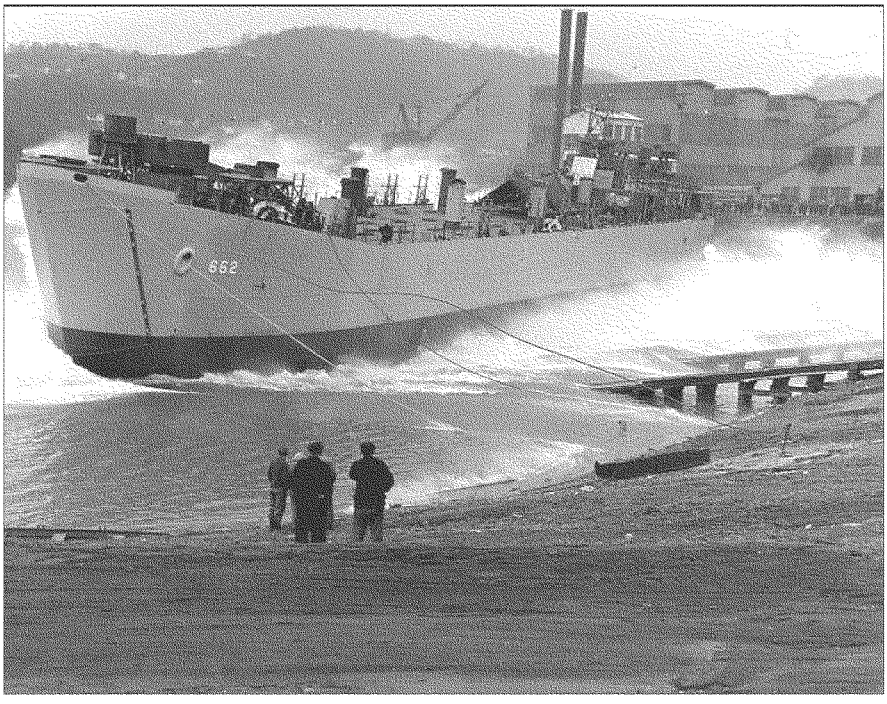

Plate 2-13. Launching of LST 662 at Ambridge in 1944

shoulders of the taxpayers. Congress has continued to do its bidding in return for improper favors, and even strong Presidents have been unable to prevail against it in the public interest" (Harold L. Ickes, March 26, 1951 Maass Papers, Folder 467). The fact that Ickes had served as U.S. Secretary of the Interior from 1933-1946 may have colored his views on the Corps of Engineers, as the Interior Department has historically been at odds with the Army Corps of Engineers and the Department of Agriculture. Although he had helped to form the Progressive Party, in 1932 he led liberal Republican support for the Democratic candidate, Franklin D. Roosevelt, who subsequently appointed him Secretary of the Interior. Ickes ardently supported social reform and conservation of natural resources.

Between 1940 and 1970, the Louisville District contributed greatly to the success of the American armies overseas. Although many of the Corps districts resumed predominantly civil works after 1945, the Louisville District continued to have a military mission during the Cold War, with major involvement during the Korean War (Johnson 1975:209). The Indiana and Hoosier Ordnance plants were re-fitted, and proving grounds and warehouses were constructed. Additional barracks were constructed at Fort Knox and Fort Campbell as well (Johnson 1975:225). The war efforts altered the nature of river commerce. Prior to 1941, the bulk of the river trade consisted of coal and steel, and flowed mostly downstream. During the war, there was a shift in commodity to petroleum products. By the 1950s, diversification and volume on the river had vastly increased, and tonnage upstream and downstream had become equal. River traffic, nearly extinct by 1917, had become so large by the end of the Korean War that modernization of the navigation system began - this time without the great struggles of the past (Johnson 1975:227).

Originally, the canalization project on the Ohio planned for 54 lock and dam structures. The elimination of 40, 42, and 54 reduced this number to 51. In 1953, a modernization project began in order to meet the increased volume of traffic and size of tows. Fifty-one dams and single locks were to be replaced by 19 dams and dual locks. This modernization project will be accomplished upon the completion of the Olmstead structure is completed. By the 1950s, the success of the Ohio River System was the pride of the Ohio Valley. Articles of its success appeared in most major newspapers and magazines, including the National Geographic and the New York Times. The November 20, 1955 issue of the *New York Times* ran a large story entitled "The Ohio Becomes Industrial Aorta". It proudly listed the achievements of the "roster of companies that . . reads like and expanded "'Whos Who' of American industry," calling the Ohio Valley the "World's Mightiest Industrial Area" (*New York Times,* November 20, 1955).

In the mid-20th century, civic and business groups, and the industries they represented, constituted a powerful political force. In 1961 they produced a large advertisement insert in the New York Times in an effort to attract industry and labor to the Ohio Valley (New York Times October 29, 1961 Section 11). Accusations of "pork" spending still surrounded the issue of Ohio River improvement, even in the 1960s. The April 28, 1964 issue of the OVIA News Letter addressed these accusation head on. This issue came after the devastating Ohio Valley flood in March of 1964. As a preemptive strike against opponents to the Public Works Appropriations Bill for Fiscal Year 1965, this issue claimed that one and a quarter billion dollars worth of damage had been prevented for expenditures of $657 million (OVIA April 28, 1964).

LATE-20TH CENTURY

The Conservation Movement of the early-20th century generally saw the Corps in a good light, as conserving water, preventing floods, erosion, forests, and finding multiple uses for natural resources while ensuring adequate protection. The Environmental Movement of the 1960s and 1970s, in contrast with the earlier Conservation Movement, criticized the Army engineers. In many eyes, the development of natural resources for economic benefits no longer justified a project. Long term environmental quality became an important issue. The Army engineers, who had generally been viewed as proponents of the conservation of natural resources now found themselves on the defensive. Environmentalist accused the Corps of destroying the natural environment with water resource development programs, and devising "make work" projects. The Corps found themselves embroiled in public protests and legal actions to stop various projects. This led to increased commitment on the Corps part to give consideration to all environmental features of navigation and flood control projects.

During this period, OVIA continued its uncompromising promotion of navigation improvements, lobbying Congress, and expending considerable resources on educating the public on Ohio River navigation issues. Pamphlets, such as one produced in 1964, presented the history and future goals of the organization to the public. It emphasized that OVIA promoted the interests of public-minded citizens, community organizations, river operators, agricultural interests, and leading industries including coal, oil, steel chemicals, electric power, and aluminum. The pamphlet emphasized the benefits that navigation improvements had yielded, including a doubling of tonnage of commodities shipped on the river in the previous 15 years, recreational developments, flood control, cleaner water, and job creation. This particular pamphlet was aimed at making the public aware of recent proposals to impose a toll on waterways, stating that it was a "breach of faith" of the government, and such a toll would "have a retardant effect on the Ohio Valley expansion, and remake the existing complex social, economic and industrial map which has been drawn in 175 years of toll-free waterways in the Nation." These tolls would "remove the corner-stone of the Valley's future, the orderly development and economic progress of the Ohio Valley." OVIA considered itself the guardian of the Ohio River navigation system, and the leader and catalyst for the modernization project for nineteen locks and dams begun in 1954. Leading members of the group included the presidents of the Mississippi Valley Barge Line, the Ashland Oil and Refining Company, Olin Mathieson Chemical, Armco Steel, National Steel, Island Creek Fuel & Coal, Consolidation Coal, American Electric Power Service, Wheeling Steel, Johnson & Higgins, Cincinnati Gas & Electric, Canal Barge Co., Standard Oil, and the Kanawha Sand & Gravel (OVIA 1964).

Criticism against the Corps of Engineers never ceased despite the apparent success of slackwater navigation on the Ohio and other systems. Excesses of waterways lobbies only exacerbated the image of "pork". In 1968 a major source of ridicule and disgust for the waterways lobby surfaced with the plans of the National Rivers and Harbors Congress to "erect a 'monumental building' on the public mall between the Jefferson Memorial and the Washington Monument." The article, although supposedly written against the lobby group, directed most of its heat against the Corps of Engineers, quoting from Arthur Maass' book for ammunition. Whether or not the Corps of Engineers had anything to do with the plans is not discussed, rather, it is assumed to be the case (*Free Press* April 10, 1964).

According to Johnson (1975), the comprehensive program for the development of water and related land resources between 1936 and 1973, had a revolutionary effect on "living standards and life quality in the Ohio River Basin" (Johnson 1975:3). Although it is difficult to measure the

social and economic impact that dependable, low-cost navigation on the Ohio River Basin had on riverside communities, it is clear that the impact has been enormous. The inland waterways system attracted steel plants, chemical factories, petroleum refineries, coal and coke industries, power generators, and scores of other industries. These industries in turn attracted people in search of employment, and these people often comprised a specific ethnic group. Secondary industries and commercial establishments grew around these communities to serve the growing population. This chain reaction of growth became especially strong after World War II. Johnson reports that from 1950 to 1960 alone, the population of Louisville increased 24-percent, retail sales increased 54-percent, and tonnage moving to and from the port increased about 80-percent (Johnson 1975:250).

ESSAY ON SOURCES

Research into the politics of the Ohio River Navigation System began by preparing a bibliography of relevant sources. Pittsburgh repositories included the Hillman Library at the University of Pittsburgh, the Carnegie Public Library of Pittsburgh, the Carnegie Public Library storage warehouse, and the library and archives of the Historical Society of Western Pennsylvania at the Senator John Heinz Pittsburgh Regional History Center. Additional repositories consulted included the Library of Congress, the Libraries of the University of Maryland, and the archives and library of the U.S. Army Corps of Engineers, Office of History at Fort Belvoir, Virginia. During the course of this project, many internet resources also provided valuable information. In particular, the *Biographical Directory of the United States Congress* at http://bioguide.congress.gov proved invaluable for biographical and legislative information on members of Congress.

Leland R. Johnson's historical studies of the U.S. Army Corps of Engineers provided general information on the development of the Ohio River Navigation System. These included *The Ohio River Division, The Davis Island Lock and Dam, 1870-1922,* and *The Falls City Engineers.* Other useful books covering general background of the navigation system included the works of Charles Ambler, Darrel Bigham, and Carter Goodrich.

Publications of the Ohio Valley Improvement Association, and the works of Harold Moulton (*Waterways Versus Railways)*, and Herbert Quick (*American Inland Waterways)* in particular, gave insight into contemporary thought and literature on politics, technologies, and public opinion.

Essential technical reports included Albert Gallatin's *Report on Roads and Canals*, the *Annual Reports of the Chief of Engineers, U.S. Army,* and the *Preliminary Report of the Inland Waterways Commission.* Contemporary newspapers and periodicals, in particular, the *Military Engineer,* the *Waterways Journal,* the *National River and Harbors News,* also proved invaluable.

The papers of Arthur A. Maass, at the Office of History archives for the U.S. Army Corps of Engineers, Samuel P. Hays' *Conservation and the Gospel of Efficiency, The Progressive Era*, by Lewis Gould, and *Structures in the Stream,* by Todd Shallat, all provided valuable historical analyses of the operations, public relations, political climate, as well as a broader historical context for the events surrounding the development of Ohio River navigation. While a fascinating source of information, the *Roads and Canals* series available at the Corps' library in Fort Belvoir, ends in 1890, and does not include the period of intensive work, both physically and politically, on the Ohio River Navigation System. The *Rivers and Harbors* series at the library proved more useful, as it contains the vast majority of pertinent official documents, and legislation on navigation development during the period of intense interest in Ohio River navigation development. Although the documents found within this compilation are generally available within other legislative collections, its usefulness lies in the fact that it focuses on documents relating to river and harbor development.

Perhaps the most useful primary source, the *Congressional Record* was essential for its exhaustive coverage of Congressional debates, committee reports, bills, speeches, and Congressional commentary, and statistics. Finally, the help and guidance or Corps historian Dr. Martin Reuss, has been greatly appreciated throughout the duration of this project.

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CHAPTER III

COMMUNITY GROWTH, ECONOMIC DEVELOPMENT, AND THE EFFECTS OF THE OHIO RIVER NAVIGATION SYSTEM

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THE CONTEST FOR THE MIDDLE AND UPPER OHIO RIVER VALLEY AND THE ORIGINS OF URBAN SETTLEMENT

The Ohio River as an Eighteenth-Century Cultural Divide

Many of the first towns in the Ohio River Valley developed out of or around military fortifications during the second half of the eighteenth century. The course of urbanization therefore reflected much larger, indeed international, political developments, first between England and France, then between England and her American colonies. A third geo-political dimension involved continuing land disputes with Native Americans. The Ohio River Valley, especially that section between Pittsburgh and Cincinnati, became a dividing line between the protagonists and one of the most important scenes in which these dramas were played out between 1754 and 1795. A basic understanding of these larger events is therefore necessary to understand the course of urban development in the river valley.

When Euro-American settlers began to filter over the mountains from the East and arrive in the Ohio country in the eighteenth century, they found few Native Americans who were long-time residents of the area. Although the land abounded with game, only small Indian hunting camps and a few villages were found. Most Native Americans in the Upper Ohio River Valley at that time had been displaced from homelands farther to the east by encroaching European settlement. Hunting and raiding parties of Shawnee, Delaware (originally from eastern Pennsylvania, southern New York and New Jersey), Wyandot (an amalgam of Hurons, remnant Petun, and Neutral), Mingos (Ohio River Iroquois), some Cherokee, Miamis (also known as the Twightwees, who were resident in northern Ohio), and perhaps a few Tuscarora (an Iroquoian-speaking group native to North Carolina who journeyed north to live with the Iroquois in New York after the Tuscarora War from 1711 to 1713) roamed throughout the area. However, few villages or permanent settlements of these displaced native peoples were found.

There were some signs in the landscape, however, of an earlier human occupation of the river valley. Early European maps sometimes recorded the locations of abandoned Indian agricultural fields (usually called "old fields"), and what some early visitors interpreted to be abandoned towns or villages marked by large earth mounds or mound complexes. The cartographers sometimes attributed these sites to the Shawnee, the most numerous and often the most hostile of the Indians that the settlers encountered. When Europeans first saw them, these old clearings were overgrown with weeds, thistles, and prickly locust (see Briceland 1991: 34). But there seemed to be little possible relationship between the size of these former clearings and the small numbers of Native Peoples the settlers encountered. These abandoned patches, however, could be re-cleared much more easily than the surrounding virgin forest and therefore became desirable sites for early European homes, settlements and agricultural fields.

In addition to these "old fields", there were other signs of an earlier, more widespread, and more populous human occupation. Stone implements, pottery, and human burials were soon unearthed as Europeans began to cultivate the soil. Visible, too, were the well-worn routes of trails that crisscrossed the ridges and river valleys, where they also provided the first land routes for the first European settlers.

In the Kanawha, Potomac, and Ohio River Valleys, especially, many large earthen mounds and mound groups, obviously man-made, were evident (Figure 3-1). These mounds frequently occurred at or near the mouths of tributaries of the Ohio River, so it was impossible for the early settlers to

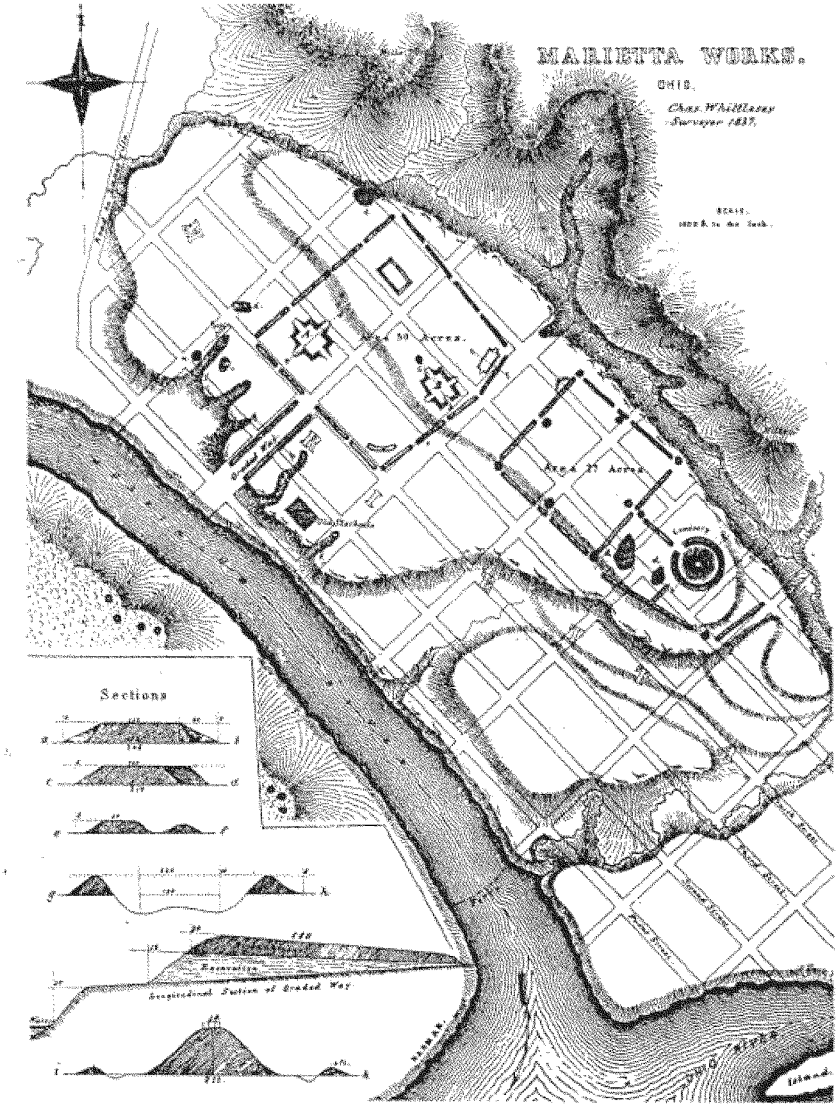

Figure 3-1: The prehistoric earthworks and mound at the confluence of the Muskingum and Ohio rivers, Marietta, Ohio, as drawn by Squier and Davis in 1848. From Silverberg (1968: 31).

ignore them. The large mounds at the mouth of the Muskingum River, the future site of Marietta, Ohio, for example, were first noted by General Samuel H. Parsons while on military duty in the river valley in the 1780s, and knowledge of them was communicated to Ezra Stiles, then president of Yale College (Silverburg 1968: 26). The Marietta mounds were incorporated within the new town's plan, and a map of them was prepared when Massachusetts and Connecticut men from the second Ohio Company arrived to begin the construction of Marietta in the winter of 1787-1788. Prehistoric mounds and mound complexes also once stood at many other Ohio cities including Circleville, Chillicothe, and Cincinnati, though most were ploughed away in the early days of settlement (Jakle 1977: 71).

Europeans developed various explanations to account for these artifacts, trails, and earthen mounds that were debated for the following century. It was obvious, however, even to the most casual observers, that the number, distribution, and size of the abandoned agricultural fields, village sites, mounds, and aboriginal artifacts far exceeded the number and, some whites thought, the intellectual and technological capacity of the sporadic Native American groups scattered throughout the area. The architectural complexity and sophistication of the mounds and the numerous abandoned sites evident across the landscape provided a sharp contrast that the European mind interpreted to be the result of a cultural disjunction. Europeans rationalized the construction of the impressive mounds, which obviously had required the coordination and expenditure of considerable human labor, by appeals to Biblical or classical "explanations." Carthaginians, lost Israelite tribes, Assyrians, and other Old World cultures known to have built similar structures were also proposed as the architects of the North American mounds. Another long-held view attributed the mounds to an extinct race of "moundbuilders."

These early European explorers and settlers were unaware that the comparatively simple bands of migratory native hunters and horticulturists of their own day were the products of more than a century of cultural upheaval, dissolution, and widespread geographical relocation. This cultural turmoil had been precipitated beyond the curtain of the Appalachian Mountains by the development of sustained European settlement on the eastern seaboard beginning in 1607 and by related socio-political changes within other Native American cultures.

Archaeologists have only recently begun to reconstruct the cultural and historical threads that knit together the native cultures of the Late Prehistoric and Protohistoric periods in the Ohio River Valley with the more familiar named tribes of the Historic period. The Late Prehistoric peoples of the Fort Ancient Tradition, for example, were once numerous in the Ohio River Valley; however, the rare historical and even more limited archaeological data for the immediately succeeding Protohistoric period, just prior to the time of the first contacts between Native Americans and Europeans, indicate that by A.D. 1650-1700 few Native Americans permanently resided in the Upper Ohio River Valley.

The Upper and Middle Ohio River Valley in the Military Contests of the Eighteenth Century

The pattern of settlement in the Upper and Middle Ohio River Valley during the second half of the eighteenth century was greatly affected by larger European political struggles, by nearly constant hostility between settlers and Native Americans, and by the American colonists' own struggles for independence from Great Britain. In contrast to the relative peace that prevailed along Virginia's northwestern frontier in the first half of this pivotal century, every decade in the second half was influenced, often extensively, by some form of military activity. One result of this military turmoil was that permanent settlements and the establishment of urban centers in the Upper Ohio River Valley were delayed until later in the century.

French claims to dominion in the Ohio drainage were based on the precedents set by their early explorations. Joliet's discovery of the western end of Lake Erie in 1669 brought within the French sphere the last of the Great Lakes to be discovered by Europeans. French exploration south of Lake Erie began well into the eighteenth century. The southern expedition of the Baron de Longueil to subdue the Chickasaw Indians in 1739 traversed Lake Ontario and Lake Erie to Niagara Falls. From there, he proceeded down the Allegheny and Ohio Rivers (which the French considered to be one river, *La Belle Rivi—re*), and from the modern day site of Pittsburgh down the Ohio into the American interior via the Mississippi River. Ten years later, another French expedition, under the command of Celeron de Blainville reasserted French claims to the Ohio River in the face of the increasing encroachment of English traders.

Britain's claims to the Ohio Valley rested on their rejection of LaSalle's boast that he had seen the Ohio River in 1669 as well as on the Batts and Fallam expedition in the seventeenth century and the penetration that English fur traders and settlers were making by the time that hostilities commenced in 1754. British traders and settlers also began to move into the Shenandoah Valley, the South Branch and Patterson Creek Valleys, the Greenbrier Valley and to the headwaters of the Monongahela River (a major tributary of the Ohio River) during the 1730s and 1740s.

English claims were further strengthened by the formation of the Ohio Company in 1747 for the express purpose of developing and settling lands in the Ohio River drainage for England. Many of Virginia's most prominent and wealthy men were partners in the Ohio Company and saw it not only as a way to acquire personal wealth through control over vast amounts of land but as a way of substantiating their own and England's claims against France.

The Ohio Company erected a trading post on the Potomac River at Will's Creek, Maryland, (now Cumberland, Maryland) before 1752, and it was to that place that the scout and compatriot of George Washington, Christopher Gist, moved his family from the Yadkin River of North Carolina in 1750. Gist's mission for the Ohio Company was to explore the lands of the Ohio River Valley, one of the first men to do so. He first traveled through what is now western Pennsylvania and into Ohio in 1750. This trip also strengthened Britain's claims to the area.

Gist was sent out again from Will's Creek in November 1752 in the company of the Delaware Indian Nemacolin and Thomas Cresap to scout out suitable lands for settlement south of the Ohio River. The objective was to define the most convenient route for a road between Will's Creek and the Monongahela River, where the Ohio Company wanted to erect one of its forts/trading houses. The trio carved out a rough wagon road from Will's Creek to the Youghiogheny River, a tributary of the Monongahela River in Pennsylvania (Buck and Buck 1967: 66). Between 1752 and 1754, this trail was expanded and was followed in 1755 by troops under the command of Major-General Edward Braddock, after whom it was called the Braddock Road. Later, it was known as the Cumberland Road. This route later became the basis for the National Road, today's U.S. Route 40. Together with the later Forbes Road (U.S. Route 30) across Pennsylvania, the Braddock Road became a primary overland route for settlers traveling to the Ohio River Valley in the late eighteenth and nineteenth centuries.

In June, 1752 Gist and three representatives of Virginia met with the Indians at Logstown, the major historic-period Indian town on the Upper Ohio River. The site of this important Indian settlement is near present-day Ambridge, Pennsylvania. In an attempt to secure better access to trade goods, the Indians at the Treaty of Logstown made two important concessions. They permitted the English to erect two forts on the Ohio River and to allow English settlement in the land south of that river.

The French were alarmed at the English and Ohio Company overtures in the Ohio river Valley, and in response they erected three fortifications in northwestern Pennsylvania in 1753 and 1754. They also sent a force down the Allegheny River to the present-day site of Pittsburgh where they removed a band of Ohio Company men who were constructing Fort Prince George at the headwaters of the Ohio River. In place of the Ohio company post, the French erected fort Duquesne.

The spring and summer of 1754 saw further military action culminating in July with the defeat of Virginian forces under a young George Washington at Fort Necessity. After this time, all of southwestern Pennsylvania/northwestern Virginia remained under the military thumb of the French and their Indian allies. An English military expedition under Major-General Edward Braddock was dispatched the following year to oust the French from control of the headwaters of the Ohio, but the column was attacked within the boundaries of the present-day town of Braddock on the Monongahela River on July 9, 1755 and suffered great losses.

Braddock's defeat encouraged the Indian allies of the French to attack all the English settlements in the western country. The entire curtain of English settlement was pushed back east, and Winchester, Virginia, at the mouth of the Shenandoah Valley again became the western outpost of English settlement in Virginia. The thinly scattered English settlements that did remain west of Winchester were poorly defended by frontier forts and ill-supplied militia. As a result, they remained in constant danger of attack.

In 1756, Virginia attempted to mount an expedition against the Shawnee Indians in Ohio under the command of Major Andrew Lewis, a prominent military, political, and social leader of colonial Virginia. The expedition, known as the Sandy Creek expedition, failed utterly and only reinforced the lessons learned earlier during Braddock's campaign about the difficulties of supplying an offensive military force in a frontier setting where roads were primitive or non-existent and where there were no towns or commercial centers to supply food, equipment, and other essentials.

Another British military expedition under General John Forbes succeeded in driving the French from Fort Duquesne in November 1758. Over the next several years, the British constructed Fort Pitt at the confluence of the Monongahela and Allegheny rivers that marks the origin of the Ohio River. After the fall of Fort Duquesne, the prosecution of the war shifted to other theaters, and after the fall of Quebec in 1759 and Montreal in 1760 the fighting ceased. A treaty however, was not signed for three additional years.

Settlers in northwestern Virginia and southwestern Pennsylvania were anxious to return to their abandoned settlements and to push even farther westward into the new lands of the Ohio River Valley. The war had sealed France's fate in North America, but the renewed encroachments of English settlers on their lands promoted continued conflict and warfare the Ohio Valley Indians. In May 1763, Fort Detroit was attacked by a force under the leadership of the Ottawa chief, Pontiac. Later in the month Shawnees and Delaware's also attacked Fort Pitt, and during the summer other British posts fell. Forts Detroit, Pitt, and Niagara remained in British hands, and British forces put down the rebellion (which has come to be known as Pontiac's Rebellion) during 1764. These events further delayed but did not halt the re-population of the western frontier. By the summer of 1763, for example, more than 50 people had already re-established themselves as far west as the Greenbrier Valley (Rice 1970; Rice and Brown 1993: 26).

The British response to the continued Indian threats to settlers was to issue the Proclamation Line of 1763. This forbade further white settlement west of the Allegheny Front, a dictate from the

offices in Whitehall that did nothing to please either individual settlers or the land speculators of such companies as the Ohio Company. Line or no line, settlers began to move back to the frontier almost as soon as the most recent fighting had stopped.

Between the formal cessation of hostilities in 1764 and the outbreak of Dunmore's War in 1774, there was a decade of relative peace if not calm during which additional Euro-American settlements in the Trans-Allegheny region were made, either illegally or legally after the negotiation of several important treaties. The Treaty of Fort Stanwix (at Rome, New York) in November 1768 as well as the Treaty of Hard Labor and the Treaty of Lochaber (October 1770) with the Indians effectively moved the dividing line between white and red lands farther west. In the Treaty of Fort Stanwix, for example, the Iroquois agreed to a dividing line set at the Ohio River. The few Shawnee and Delaware present at the treaty did not participate, however, and did not sign the treaty. The agreement only added to their resentment and set the stage for continued hostilities with white settlers (Buck and Buck 1939: 114). To the English, the agreement secured all of the land west of the Allegheny Front to the south bank of the Ohio River for settlement. Between 1764 and 1774, thousands of new settlers flocked to the area to set up farms, villages, mills, and towns.

The general conditions of peace that prevailed between 1764 and 1774 began to unravel in 1773 as it appeared to the Indians that settlers were waiting restlessly to cross over to the north side of the Ohio River. Britain had maintained troops at Fort Pitt to keep the lines of communication down the Ohio River and into the Illinois country open, but British troops were withdrawn from this seminal post in 1772 leaving no professional military force in the Upper Ohio to mediate or resolve problems with the Indians.

Several isolated incidents soon exacerbated the tensions along the western frontier in 1773, and in February 1774 Indians killed a number of whites on the Virginia border. The following April, several Indians were killed in a canoe near Wheeling and the father, brother, and sister of the Mingo chief Logan also were killed near Wheeling. Aroused by these incidents, Virginia Governor Lord Dunmore raised a force for the protection of the frontier settlers that was stationed at Wheeling. Dunmore also raised several other armies to take the war into the Indian lands on the north side of the Ohio. This move was opposed by the followers of Chief Cornstalk at the Battle of Point Pleasant, fought on October 10, 1774, where the Kanawha River joins the Ohio. Although nominally a victory for Dunmore, the Virginians lost some 46 dead. After some additional military action, a temporary treaty was concluded at Camp Charlotte by which the Indians promised not to hunt or travel south of the Ohio River. Dunmore strengthened his detachment at Fort Dunmore (as he had renamed Fort Pitt) and at other garrisons along the Ohio River (Hughes 1932: 37-42; Rice and Brown 1993: 31-36).

While Lord Dunmore pursued military adventures in Ohio and set the stage for renewed hostilities with the Indians that characterized the American Revolution in the West, most citizens in the western Virginia counties concerned themselves with building homes and small communities and laying out farms. Larger political events soon overtook these mundane concerns as relations between England and her American colonies worsened and then exploded into open war in April 1775.

Like other colonies, Virginia raised line regiments to fight in the major battles in the eastern theater of the Revolution, but the primary threat to her frontier settlements such as those on the South Branch of the Potomac and the scattered settlements arrayed southeast of the Ohio River came from the "Ohio Indians" on the north side of the river who allied themselves with the British. By the time of the Revolution, the leading edge of American settlement on the frontier

extended west of the South Branch and Patterson Creek areas into the Tygart, Cheat and Monongahela drainages. Most of the Indian raids on these outlying Virginian settlements and individual farms during the American Revolution took place in what today are the West Virginia counties bordering the Ohio River. These scattered and small settlements, established or re-established between 1763 and 1774 or 1775, served as buffers against raids on the more heavily populated South Branch and Patterson Creek Valleys.

The British presence at Fort Mackinac and Fort Detroit, however, provided ample opportunity for dissembling amongst their Indian allies against the Americans. The Indians were held firmly in the economic clutch of the British fur trade and were antagonized by years of illegal American settlement on their lands. The 1763 proclamation line that divided English from Indian claims had been routinely ignored by settlers, and British machinations to play off the western Indians against the Iroquois Confederacy contributed to the smoldering hostility among the Ohio tribes (Downes 1968: 140-151).

Throughout the American Revolution, the Ohio River continued to define an important cultural divide between American settlements to the east and south and the Indian lands on the north and west sides of the river. Many of the first settlements in the Ohio River Valley therefore were military fortifications and camps erected to protect the western door of the 13 colonies. A number of these fortifications eventually were built, often at sites that later developed into the earliest towns in the Upper and Middle Ohio River Valley. The presence of these posts and smaller "frontier forts" conveyed a measure of protection to settlements and farms that clustered near them, but almost always the posts were poorly supplied and inadequately garrisoned by militia units (e.g., Carlisle 1978). For example, in September 1775 Virginia sent John Neville of Winchester, Virginia, a veteran of Dunmore's War, and 100 militiamen to occupy Fort Pitt (Pittsburgh). Neville remained in command there until April 1777 and participated in several treaty negotiations with the Indians. Neville's—and therefore Virginia's—titular military authority also extended down the Ohio River to include command of the small frontier fortifications erected at the site of Wheeling (originally Fort Fincastle, later replaced by Fort Henry) and Point Pleasant (Fort Blair, burned by the Indians in 1775 and replaced by Fort Randolph). Neville maintained communication with the subordinate commanders of these posts, and periodic attempts were made to provision them from Pittsburgh via the river (Carlisle 1998: 12-13). Thus, even at this early time, Pittsburgh exerted a regional influence in the Upper Ohio River Valley that extended down the river at least as far as Point Pleasant and the Kanawha River.

Neville, like many other prominent military men of his day also combined land acquisition and speculation in the fertile Ohio River Valley with his military duties. As early as 1774, in fact, he had purchased some 14,000 acres of land on the Ohio frontier. Thousands of acres of this property were located a short distance above the confluence of the Great Kanawha and Ohio rivers. Although Neville's plans for this property are unknown, the large amount of land buying and selling he conducted elsewhere in the valley suggest that he hoped eventually to make a profit by selling off lots to individuals or to land companies, or by establishing one or more towns (Carlisle 1998: 8-9). Neville was in good company. Lord Dunmore had made many large grants of land in the Kanawha River Valley to other Virginia land speculators. George Washington himself eventually acquired some 35,000 acres of land in the Ohio and Kanawha valleys and even dispatched men to build houses, barns, and other structures on his Kanawha River parcel in 1775. Here he hoped to settle immigrants from Europe, but the onset of the Revolution and the resumed Indian hostility on the western frontier forced him to abandon this work (Rice and Brown 1993: 31).

Based on George Rogers Clark's successful campaigns against Vincennes and Kaskaskia, the Americans assembled several other expeditions to carry the war to the British and their Indian allies across the Ohio. The Western Department of the Continental Army, headquartered first at Fort Pitt and then at Fort McIntosh (constructed in 1778 on the north side of the Ohio at present-day Beaver, Pennsylvania), attempted but failed to sustain military expeditions against the British at Fort Detroit under General Edward Hand and, in 1778, under General Lachlan McIntosh (Carver 1975; Carlisle 1979). The inability of McIntosh's expedition, to penetrate the Ohio country presaged the failure of two later expeditions mounted by General Josiah Harmar (1790) and General Arthur St. Clair (1791). Military ineptitude, poor planning, lack of familiarity with Indian battle tactics, and, perhaps especially, poor military training and the lack of towns and settlements large enough to supply these expeditions severely hampered the American military in the Ohio River country from the French and Indian War into the Indian Wars of the 1790s. The inability of the American military to guarantee protection for settlers in turn must have retarded but did not prevent settlement in the river valley and the establishment of new communities.

Indian rights to lands north and west of the Ohio River defined at the second treaty at Fort Stanwix in 1784 were reaffirmed by treaties concluded at Fort McIntosh (1785) and at Fort Finney in January, 1786. Fort Finney was another of the military posts of the Ohio River Valley. It was first located at the junction of the Miami and Ohio rivers, but the garrison and name were moved in the summer of 1786 to the falls of the Ohio River opposite present-day Louisville, Kentucky. The legal restrictions imposed by these treaties had little effect, however, on the movement of squatters into Indian territory.

The number of whites living north of the Ohio River ca. 1785-1790 is difficult to estimate. In accordance with the Treaty of Fort McIntosh in 1785, Ensign John Armstrong was ordered by General Josiah Harmar to remove the white families who had settled there between Pittsburgh and Wheeling. Armstrong reported that 600 families already had settled on the Hocking and Muskingum rivers, and that 1,500 people then occupied the banks of the Miami and Scioto rivers (Roseboom and Weisenburger 1986: 51). Kohn (1975: 92, note) has estimated that perhaps 4,200 whites could be found in the entire Northwest Territory in 1790 at a time when the Indian population ranged from perhaps 2,000 to 2,500.

By 1786, construction of American settlements and forts had followed the twists and turns of the Ohio River as far west as the present-day border of Ohio and Indiana. Fort Harmar, for example, was established by 1785 at the mouth of the Muskingum River (Figure 3-2). The town of Marietta, Ohio—the first legitimately authorized community in the Northwest Territory—subsequently was laid out here by the Second Ohio Company in 1788. Fort Harmar joined other Ohio River fortified settlements at Fort Henry (Wheeling, West Virginia) and Fort Randolph (Point Pleasant, West Virginia). Fort Steuben, at present-day Steubenville, Ohio, was set up in August, 1786 and was soon joined by Fort Knox, built at Vincennes on the Wabash River in 1787. Another post, Fort Washington, was built at present-day Cincinnati in the autumn of 1789. The last remained the most important of the American posts on the Ohio throughout the period of the Harmar, St. Clair, and Wayne expeditions. It was to Fort Washington that General Anthony Wayne and his "Legion of the United States" marched in April 1793 after leaving their encampment at Legionville on the Upper Ohio River near the site of Logstown, the old Indian town not far below Pittsburgh (Prucha 1969: 34; Carlisle 1991). It was only after Wayne's victory at the Battle of Fallen Timbers in northwestern Ohio in 1794 and the conclusion of the Treaty of Greeneville in 1795 that the threat of Indian attacks on Upper Ohio River settlements was eliminated and the development of towns and communities in the river valley could proceed unimpeded.

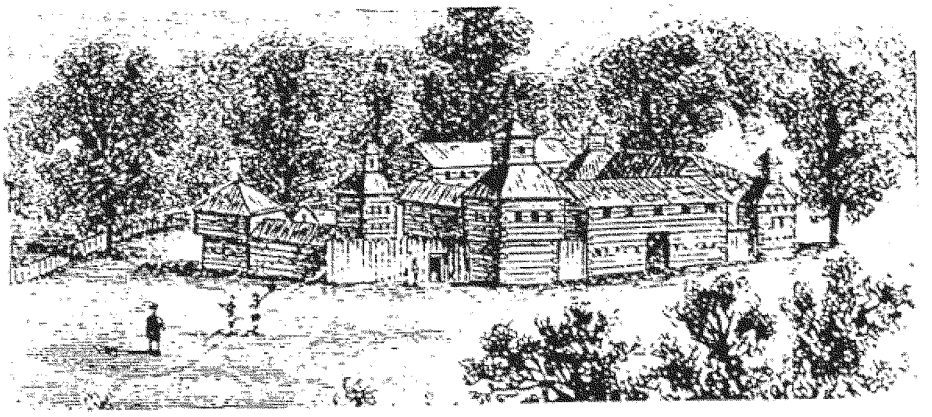

Figure 3-2: Fort Washington, constructed at the present site of Cincinnati, Ohio. From Prucha (1969: between pages 206 and 207).

Political Subdivision of the Land as a Prelude to Settlement

Throughout much of the eighteenth century both Virginia and Pennsylvania laid political claim to what today is southwestern Pennsylvania. Prior to the American Revolution, several land schemes were advanced to erect an entirely separate government in a large tract of land that included most of present West Virginia as well as part of Kentucky. "Vandalia" was the most famous of these proposed schemes. Plans called for a capital to be located at the junction of the Great Kanawha River and the Ohio River, where Point Pleasant, West Virginia is found today. The proposal foundered at the commencement of the Revolution with Indian attacks on western settlements (Hughes 1932: 36). In 1775, petitions were circulated to admit nearly this same large block of land as the fourteenth colony under the name "Westsylvania," but this attempt also failed.

At the same time, Virginia's interpretation of its colonial charter placed the colony's western boundary at the Ohio River (Figure 3-3). Only two of the Virginia counties that later became part of West Virginia existed at the start of the Revolution: Hampshire (1754) and Berkeley (1772). The rest of today's West Virginia was subsumed within Fincastle County, south of the New and Kanawha rivers, Botetourt and Augusta counties, which extended across the north-central portion of the state to the Ohio River, and the District of West Augusta, set up in 1773. In 1776, Fincastle County was divided into Kentucky, Washington, and Montgomery counties. Kentucky County subsequently developed into the state of Kentucky, fueled by a 600 percent population increase between 1783 and 1790. In November 1776, Dunmore called for a separate court to be convened at Fort Dunmore (Fort Pitt/Pittsburgh) for the District of West Augusta. This was an attempt to separate this large and poorly defined territory administratively from Augusta County and to stimulate settlement by Virginian colonists. Three Virginia counties were erected within the District of West Augusta in 1776: Ohio, Yohogania, and Monongalia. Both Yohogania and Ohio counties directly bordered the Upper Ohio River and represent the first attempts to establish

political and administrative boundaries in this portion of the Ohio River valley (Figure 3-4). In 1778, the portion of Botetourt County on the west side of the Alleghenies became Greenbrier County (Rice and Brown 1993: 47-48).

Virginia's western population grew considerably after the Revolution. In 1790, it is estimated that some 125,000 lived on the west side of the Appalachians, and about 70,000 of these had taken up residence in the fertile lands of Kentucky. The 1790 population of that portion of Virginia now included in West Virginia stood at about 55,873, but only about 20,000 of these lived west of the Appalachians. By 1800 the population, particularly in the Monongahela, Kanawha, and Upper Ohio River Valleys had grown sufficiently that eight additional counties in current West Virginia had been formed, and the General Assembly also had authorized the creation of 19 new towns. Among these were Wellsburg, on the Ohio River between Steubenville and Wheeling, and West Liberty, just east of the Ohio River and north of Wheeling. Between 1790 and 1830, western Virginia's population grew 317 percent, somewhat below the nation's average of 354 percent (Rice and Brown 1993: 47-48).

The boundary dispute between Pennsylvania and Virginia over land in what is now the southwest portion of Pennsylvania remained until after the American Revolution, even though a preliminary agreement to extend the Mason & Dixon Line (which defined the southern boundary of Pennsylvania) west was reached in 1781. The dispute was not completely resolved until the survey of the line was finished in August 1786.

Not unlike its rival colony Virginia, Pennsylvania also engaged in political development of its western lands in the Ohio country, sometimes overlapping Virginia's claims. In 1773,

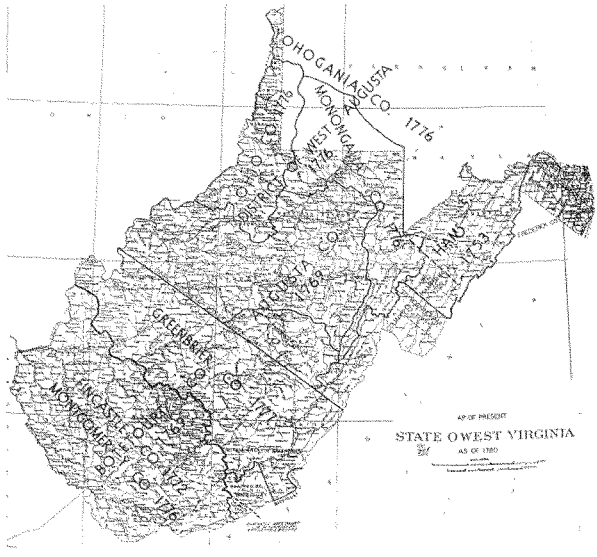

Figure 3-3: The development of Virginia counties by 1780. From Sims (1956).

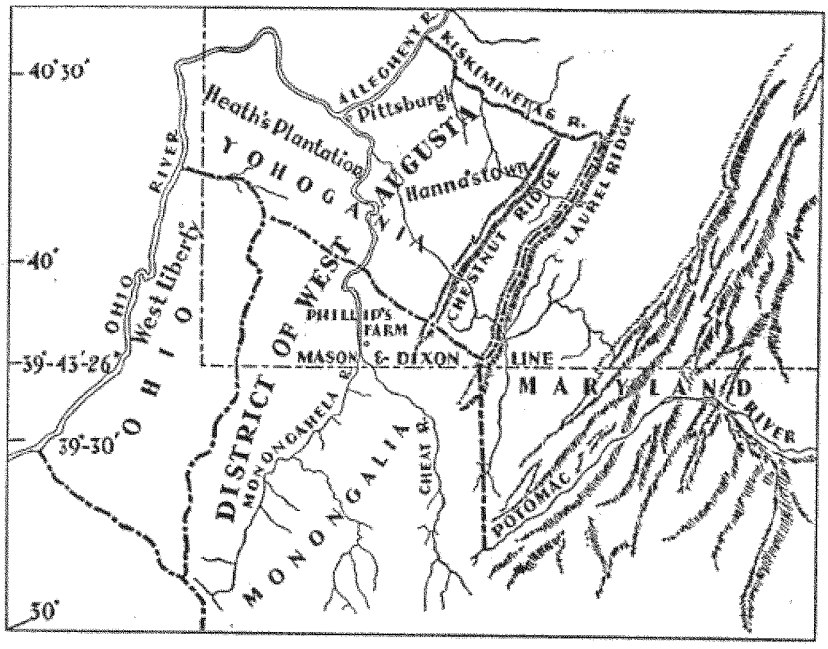

Figure 3-4: Division of the District of West Augusta in Virginia into Ohio, Yohogania, and Monongalia counties encompassing the lands of the Upper Ohio and Monongahela River drainages. From Buck and Buck (1939: 165).

Westmoreland County was set up in southwestern Pennsylvania. It became the parent county for all of the counties in this part of the Commonwealth south of the Ohio River. The formation of other Pennsylvania counties followed the conclusion of the Revolution: Washington (1781), Fayette (1783), Allegheny (including Pittsburgh at the head of the Ohio River, 1788), and Greene (1796). Beaver County, with its southern border on the Ohio River, was not formed until 1800.

Although the American army failed to subdue the hostile Indians on the north side of the Ohio River until the mid-1790s, land speculation, land claims and surveys, and political subdivision of the Ohio land bordering the river was well underway by that time. Thomas Jefferson authored the Ordinance of 1784, which, although it was never enacted, provided for the future division of the Northwest Territory into 16 to 18 prospective states. Rectangular survey of the land was specified by the Land Ordinance of 1785. Two years later, the Ordinance of 1787 established three successive stages of governance for the Northwest Territory based upon increases in population. Government in the first stage consisted of a governor, a secretary, and three judges appointed by Congress (Roseboom and Weisenburger 1986: 47, 49).

Land squatting, legislation to survey and carve up the Northwest Territory, and the lucrative potential of land speculation proved irresistible forces that all contributed to the pattern of settlement north of the Ohio (Figure 3-5). Virginia provided land grants to its veterans in the

6,570 square miles of the Virginia Military Reserve, located between the Scioto and the Great Miami rivers, for military service during the Revolution thereby guaranteeing that men with a military background would be resident in the area. Land grants here were liberal. John Neville, for example, eventually received 7,777 2/3 acres based on his rank of colonel. His son, also a Revolutionary War veteran received 7,000 acres in the Virginia Military Reserve as a lieutenant colonel. As early as November 1787 John Neville had arranged for the survey of 1,400 acres of this property, the first survey carried out in what became Washington Township of Clermont County, Ohio. John Neville died in Pittsburgh in1803 and never lived on his Ohio land. In 1808, Presley Neville laid out the small Clermont County town of Neville within his father's land on the Ohio River about 30 miles southeast of Cincinnati. Through an agent, Presley sold off town lots in Neville, which originally contained 120 quarter-acre lots. About 1816, Presley and his family moved from Pittsburgh to Neville, where Presley died in 1818 (Carlisle 1998: 39-42).

A second Ohio Company (based in New England, not Virginia) and the Scioto Company were both formed as land speculation ventures for the Northwest Territory. The Ohio Company, under Rufus Putnam and Manassah Cutler, was responsible for the establishment of Marietta at the confluence of the Ohio and Muskingam rivers in 1788. The Scioto Company, headed by William Duer (then Secretary of the Treasury Board of the United States) and Manassah Cutler arranged with Congress to purchase nearly five million acres between the Ohio Company's property and the Virginia Military Reserve. Not coincidentally, General Arthur St. Clair, then President of Congress, concurred with this land speculation plan and was, in turn supported by both companies in his bid to become the first Governor of the Northwest Territory (Roseboom and Weisenburger 1986: 52-53).

Another land speculator, John Cleaves Symmes, petitioned for and was granted the sale of a large tract of land around present-day Cincinnati as early as 1788. The Symmes Purchase fronted on the Ohio River and extended between the Big Miami and Little Miami rivers. It was largely to protect settlers in the Symmes Purchase that Fort Washington was erected at the site of present Cincinnati in 1789. This post was soon garrisoned by troops from Fort Harmer, and Governor St. Clair moved his headquarters there, proclaiming it the capital of the Northwest Territory, a move that enhanced Cincinnati's later reputation as the major city of the Middle Ohio River.

A final tract of land in the Northwest Territory (though not on the Ohio River), Connecticut's Western Reserve, was not ceded to the United States in 1786 but remained as an important and large land claim, originally set aside to compensate Connecticut citizens who had lost their property to Tory raids during the Revolution. Parts of this important chunk of northeast Ohio, which included the present site of Cleveland on the Cuyahoga River, were distributed among some 1,870 Connecticut claimants. The rest of the property was sold after 1795.

The rapid creation of new counties and towns in both the Northwest Territory and in trans-Appalachian Virginia after the Revolution was both an important reflection of population increases and settlement in those areas and a stimulus for it. Once created, the county as a legal entity helped to attract new residents by offering a place where land patents could be recorded, the services of a surveyor, and the protection of a county seat where deeds, wills, taxes, and other legal documents were settled or filed and courts where disputes were resolved. New towns therefore contested hotly for the role of county seat because they attracted both new and long-term residents from all parts of the county on a recurring basis. Lawyers and judges were also drawn to reside in and near the county seats and added to the sophistication and educational level of these frontier towns To accommodate visitors transacting legal business, the county seat also needed hotels and taverns and one or more general merchandise stores.

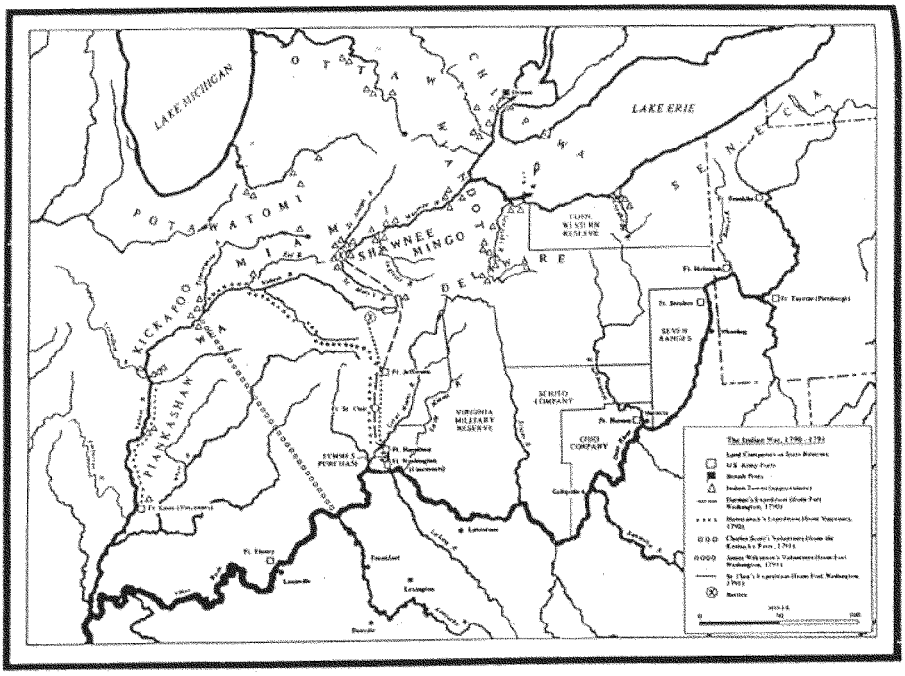

Figure 3-5: Distribution of land speculation and state reserve tracts in present-day Ohio. From Kohn (1975: 105).

URBAN ORIGINS AND THE DEVELOPMENT OF THE MAJOR TOWNS AND CITIES OF THE MIDDLE AND UPPER OHIO RIVER VALLEY

Trends in Town Formation and Development in the Middle and Upper Ohio River Valley

Permanent settlement and established urban life in the main stem of the Middle and Upper Ohio River Valley depended upon the resolution of international and local political and military conflicts. Some small towns, such as Marietta, had been planted on the banks of the Ohio in the late 1780s, and both Pittsburgh and Cincinnati had begun their long course of evolution that transformed them into the major cities. In all three cases, military fortifications at or near the new settlements were precautions against attack from Indians in northwest Ohio. The forts afforded a measure of protection for the residents of incipient towns. The need to provision and supply the troops stationed at these posts also generated some commercial and market opportunities that supported the blossoming urban and local agrarian economies. The military setbacks suffered by the Harmar and St. Clair expeditions against the "Ohio Indians" in 1790 and 1791, respectively, retarded both rural and urban settlement in the Mid- and Upper Ohio River Valley, but after Anthony Wayne's victory at Fallen Timbers in northwest Ohio (1794) and the conclusion of the Treaty of Greene Ville (1795), the Indian threat to rapid American settlement here was over.

Settlers and elected officials of early inland towns were quick to realize the commercial importance of establishing good transportation ties to larger urban centers and to the Ohio River. As early as October 1781, for example, officials of the recently laid-out settlement at Washington, Pennsylvania, the county seat of Washington County, presented petitions to build roads to streams and rivers. The 1781 petition proposed a road from "Catfish Camp" to the "Presbyterian meeting-house in the forks of Chartiers Creek", which joins the Ohio River just a few miles below Pittsburgh. Washington residents also wanted a road to the developing Ohio River commercial center at Pittsburgh, as well as a road to connect their town with Redstone Ferry (Brownsville), an important early commercial center on the Monongahela River above Pittsburgh.. Many similar road-building petitions were filed between 1781 and 1794. Looking to the west, Washington residents and merchants also established overland transportation connections to the evolving Ohio River town of Wheeling, and a mail coach was operating between the two towns by 1811.

The formation of speculative towns by individuals, such as that at Neville, Ohio, after 1808 was one of the means by which urban centers were carved out of the Old Northwest wilderness. The small, compact, and regular town lots were often easier to sell to new arrivals who had little cash, and the presence of blacksmiths, millers, and other artisans in these towns could also make the speculator's larger tracts of nearby rural property more valuable as the town provided services, amenities, and a market for the sale and redistribution of agricultural products. Agricultural and manufactured goods also could be traded up and down the Ohio River, so locating a town like Neville on the river improved access to both nearby and more distant markets and directly benefited both the town and its residents. The centrality and importance of such a town was further enhanced if a land office was located in it, or if it became the county seat. Competition among the new towns of the Northwest Territory for political prominence was therefore keen.

The Effects of Some Early Transportation Improvements on Towns and Cities

The National Road and Virginia Turnpikes to the Ohio River

The first major transportation project that benefited the population growth and economic development of both inland and Ohio River towns, especially Wheeling (West) Virginia, was the National Road. The route of this road is followed today by U.S. Route 40. The road began in Cumberland, Maryland. It proceeded west and crossed the Ohio at Wheeling, then passed through Columbus, Ohio, and Indianapolis, Indiana, before terminating at Vandalia, Illinois. The National Road is historically significant as the federal government's first attempt to improve the nation's systems of internal transportation and communication. The Pennsylvania Society for Promoting the Improvement of Roads and Inland Navigation had developed and submitted to the state legislature the first transportation plan developed in the country as early as 1791; however, few individual states then had the finances needed to build and maintain roads. Private turnpike companies attempted to plug the gap, but road building at the beginning of the nineteenth century was insufficient to accommodate the nation's rapidly increasing population.

In 1808, Secretary of the Treasury, Albert Gallatin, presented his *Report on the Subject of Public Roads and Canals* and became a strong proponent for the federal government's involvement in the construction of internal improvements. Gallatin believed that the construction of roads and canals would spur the nation's economic growth, especially in the rapidly growing Midwest. An east-west road into and through Ohio was especially desired, and Congress passed an act allowing a "2 percent fund" to be collected for that purpose.

Two years before Gallatin's report, an "Act to Regulate the Laying Out and Making a Road from Cumberland, in the State of Maryland, to the State of Ohio" was passed. The survey for the road began at Cumberland, Maryland, in early September 1806 and had progressed 131 miles to the Ohio River by the end of August 1808. The surveyors proposed that the road should be covered with stone to prevent rutting and estimated the construction costs at $6,000 per mile, excluding bridges. The roadbed was to be 66 feet in width and constructed of layers of crushed stone, sand, and earth.

Towns in southwestern Pennsylvania were quick to appreciate the potential economic advantages of steering the new road through their town, and political wrangling over the road's exact course was intense. Selection of the route between the Monongahela River west to the Ohio River was especially contentious. Two routes through Washington County, Pennsylvania, were surveyed in 1815 and 1816. One led through the county seat of Washington while the other – and initially preferred -- route led through the southern part of the county. Political forces in the town of Washington, Pennsylvania, prevailed on President Madison, however, and it was he who determined that the National Road would pass through that town. This was a major coup for the small borough of Washington and a good example of how quickly such small communities could threaten larger, more economically significant urban centers by capturing transportation routes. As built, the National Road passed through Brownsville on the Monongahela River across country to Washington, Pennsylvania, and from there westward to Wheeling and the critical juncture with the Ohio River. Merchants and political leaders in Pittsburgh were both furious and frightened that the selected route of the National Road completely cut off their town while it promoted Washington's and Wheeling's direct trade and passenger traffic with the rapidly developing commercial metropolis of Baltimore.

Navigation conditions on the Ohio River upstream from Wheeling played a significant role in Wheeling's selection as the point where the National Road crossed the Ohio River. Obstructions

in the river between Wheeling and Steubenville were notorious and created hazardous travel conditions for river craft, especially during periods of low water during the summer and autumn. As a result, by the time the route of the National Road was being finalized, Wheeling already had emerged as a dry-season "point of departure" for downstream river traffic. Providing it with a connection to the new road therefore made a great deal of sense as did the fact that Wheeling lay in a line from Brownsville, Pennsylvania (formerly, Redstone Old Fort, the road's crossing point of the Monongahela River) and the center of the state of Ohio. The road's exact crossing point at Wheeling was selected to allow travelers to traverse the river on a ferry at high water and by a "good ford" during low-water. Thus, river navigation conditions, commercial considerations, and the convenience of travelers all played important roles in Wheeling's selection as the Ohio River crossing point for the National Road (Hulbert 1901: 503-504).

Construction of the National Road was slowed by a lack of funding and by the outbreak of the War of 1812. By 1813, perhaps only 24 miles of road had been built west from Cumberland. The next 18 miles were not finished until 1817, but progress improved considerably after 1816. With the exception of the road segment from Brownsville to Washington, Pennsylvania, contracts for construction of the roadbed in that state west to Wheeling had been awarded by the spring of 1817. Colonel Eli Williams, who was in charge of road construction from Brownsville west to the Ohio River, advertised the construction contracts in mid-November 1816. The following March, Thomas McGiffin, Thomas H. Baird, and Parker Campbell of Washington were awarded the construction of the road from 2 miles east of Washington to the (West) Virginia line. In 1819, the same men were awarded the contract to construct the road eastward from Washington to a point 2 miles west of Brownsville (Peyton 1996: 133, 135).

By the summer of 1818, construction of the National Road had reached the Youghiogheny River, a tributary of the Monongahela River. McGiffin, Baird, and Campbell received another contract for road construction westward from Uniontown "to the vicinity of Washington" in May 1819. Road construction had a rapid influence on the development of passenger transportation services and quickly improved the speed and occurrence of inter-city communications and travel. In August 1819, for example, a thrice-weekly stage line began operations between Washington, Pennsylvania, and Pittsburgh. From Pittsburgh, a traveler could continue by stage to either Washington, D. C. or to Baltimore, a trip that required about four days. By the fall of 1820, the National Road was complete along its length to Wheeling even though it remained unpaved from a point 5 miles east of Washington, Pennsylvania, to Wheeling until 1835. In 1821, a stage journey from the inland town of Washington, Pennsylvania, to Wheeling on the Ohio River required 11 hours. By 1837, one Washington-based stage line was running two daily departures between Wheeling and Baltimore that passed through Washington, and stage service connecting Wheeling and Philadelphia also was in operation (Forrest 1926: 842).

Travel on the National Road was at first free of charge, and large herds of cattle, sheep, and horses, plus stagecoaches, travelers on horseback, settlers moving west in Conestoga wagons, and freight wagons often clogged the route. This traffic prompted construction of numerous hotels and taverns in towns and at intervals along the road.

Construction of the road, originally heralded as a national triumph, was not matched by a continuing federal commitment to its maintenance. The often poor condition of the road only enhanced the attractiveness of river travel. Writer Charles Fenno Hoffman, commenting on the condition of the road between Washington and Wheeling recorded that "the ruts are worn so broad and deep by heavy travel, that an army of pygmies might march into the bosom of the country under the cover they would afford" (quoted in Peyton 1996: 149).

Federal allocations for road repairs between 1823 and 1827 averaged just $88 per mile. Finally, in 1829, a $100,000 appropriation was obtained for repairs to the road east of Wheeling, and between 1829 and 1835, over $1,000,000 was allocated for repairs from the Ohio River eastward (Peyton 1996: 150). As each section was repaired, jurisdiction was turned over to the states. Toll houses were then erected, and the road was operated as a turnpike. The toll gates on the road in Washington were erected in 1835. The imposition of tolls actually helped to clear the road of the earlier large flocks of live animals that were driven along it. Very large freight wagons, some with wheel rims 9 inches in width and drawn by six to eight draft horses, now appeared. Such wagons could carry five to six tons of merchandise. In the fortunate towns through which the National Road passed, it was not unusual to see these wagons filling the streets from one end of town to the other. Such wagons carried previously hard-to-get manufactured goods for sale in the general merchandise stores of towns. The road also provided access to new, more distant markets where agricultural produce from farms outside the towns was sold. Hotels and taverns in National Road towns also grew in number to feed and house the itinerant wagon drivers and stage-coach travelers.

Completion of the National Road west to the Ohio River also facilitated the delivery of the mail. This was an important consideration for the thousands of new migrants to the West and for western businessmen who sought to establish or improve their trade and other business connections with major eastern population centers. Mail service between Wheeling and Washington D.C. was initiated in 1818, even before the road itself was completed. In 1837, mail delivery from Wheeling through Washington to Uniontown in Fayette County, Pennsylvania, took just 6.5 hours, the fastest overland mail route operating anywhere in the country. This service was replaced by the "Monkey Box Line" in 1838, a series of mail coaches that also carried passengers.

Continuing problems with expensive repairs and a lack of commitment from the federal and state governments to maintain it meant that the National Road was never a paying proposition. By the 1850s, railroads, and later the development of interurban rail lines had largely usurped the road's purpose and provided better transportation for freight and passengers alike. Although the National Road continued to provide important local transportation connections and was eventually integrated into the nation's interstate highway system as U.S. Route 40, its period of true national prominence came and went in a remarkably short time between approximately 1818 and 1860.

In addition to the National Road, a number of other east-west turnpikes were constructed in the nineteenth century that connected the more settled towns of the East to the western frontier. Such roads were rare at first, but Virginia built three state and privately funded turnpikes that connected eastern Virginian towns with towns on the Ohio River (Figure 3-6). From north to south, there was the Northwestern Turnpike (today's U.S. Route 50) between Winchester, Virginia, and Parkersburg on the Ohio. Parkersburg was also the river terminus for the Staunton-Parkersburg Turnpike from Staunton, Virginia, located at the head of the Shenandoah Valley. Similarly, Lynchburg, Virginia, was the eastern terminus for the James River and Kanawha Turnpike (today's U.S. Route 60) that ran through Charleston, West Virginia, to Huntington on the Ohio River.

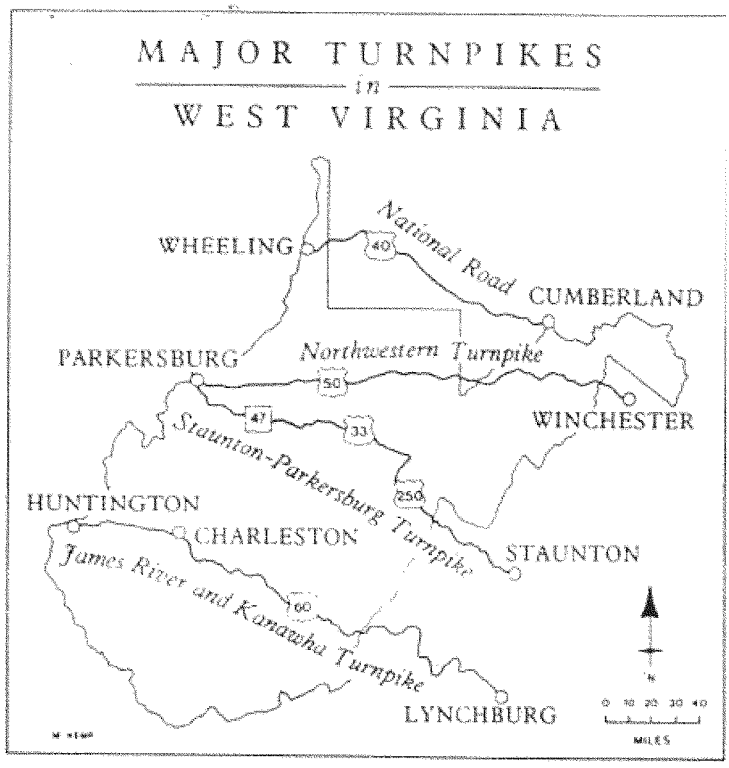

Figure 3-6: Construction of new roads in the nineteenth century linked older, more established eastern towns with newer towns on the Ohio River and improved the freight and passenger trade of both in the days before canals and railroads. From Cohen (1992: 6).

Canals

The construction of a system of canals as a stimulus to population growth and economic development in the trans-Appalachian interior was proposed in the late eighteenth century, but the dreams of George Washington and like-minded men to connect the nation's interior river valleys required the passage of several additional generations to achieve fruition. The great era of American canal construction between roughly 1825 and 1850 was frenetic but remarkably short-lived. It contributed significantly, however, to the explosive growth of the American economy between 1800 and 1860. The focus of American business during this period shifted from overseas trade to internal markets, principally on the rapidly expanding western frontier. This period witnessed multiple revolutions in agriculture, technology, transportation, energy production and consumption, industrial capitalism and production (the "Industrial Revolution"),

and a modern system of capital investments, to say nothing of the great increase in the nation's population achieved by immigration and by natural increase. The population of the country increased from about 2.5 million in 1776 to 8.5 million by 1815, and to 31 million in 1860 (Blackford and Kerr 1990: 81). In the first half of the nineteenth century, both state and federal governments also began to participate with private companies and individual investors in the creation of business opportunities and large-scale projects that were perceived as benefiting the nation as a whole and as safeguards to republicanism (Shaw 1990: 18). The canal-building era focused as never before the debate over public and private roles in the promotion of internal improvements (Carlisle 1994: 5).

The American era of canal construction began with the opening of the Erie Canal connecting Lake Erie with New York on October 26, 1825. Even before the canal had been completed, thousands of barrels of flour, grain, millions of board feet of lumber, and thousands of gallons of whiskey began flowing to New York City from the agrarian hinterlands of the state. This revolution in transportation promoted the construction of new gristmills, saw mills, and distilleries in towns along the canal route and increased the business opportunities for commercial agriculture (Blackford and Kerr 1990: 86).

The initial success that the Erie Canal enjoyed served as both an incentive and a warning to businessmen and politicians in neighboring states. Pennsylvania business interests, especially those in Pittsburgh, feared the loss of their Ohio River trade to the Erie Canal, especially when Ohio initiated two canal-building projects in the 1820s to join Lake Erie to the Ohio River at the Ohio town of Portsmouth via the Ohio & Erie Canal. In response, Pennsylvania soon entered the canal-building fray by constructing an east-west canal in three segments across much of the state. The Pennsylvania Mainline Canal, built between 1825 and 1830, required some ingenious technology. On the east, the canal terminated some 20 miles outside Philadelphia, where an early railroad connection continued into the city. The mountainous section in the center of the state between Hollidaysburg and Johnstown was crossed by winching the canal boats up the mountain side on flat cars, then lowering them down the other side to resume their canal trip.

When the canal was completed to Pittsburgh (with a separate terminus in Allegheny City, the present North Side neighborhood of Pittsburgh, but a separate municipality before 1907), Pittsburgh business interests breathed a sigh of relief. The new canal permitted more effective and economical commerce between Philadelphia and Pittsburgh but also, via a short passage on the Ohio River, allowed the Pennsylvania and Ohio Canal systems to operate in greater harmony with each other. Instead of simply diverting the New York trade from Pittsburgh to Ohio, completion of the Pennsylvania Canal system and the Pennsylvania and Ohio Canal (also called the Mahoning or "Cross Cut" Canal) through the Mahoning River Valley opened up Ohio markets to greater penetration by Pennsylvania, especially Pittsburgh, products. The production and transportation of cheese and other dairy products, wool, and agricultural produce in the valley were stimulated, and these products were soon being shipped by canal to Pittsburgh, Cleveland, and New York, and down the Ohio River to Cincinnati. Large amounts of Pittsburgh ironwares—for which Pittsburgh already had become a major center--also were transported to Ohio via canal, some 4 million pounds in 1840 and 12 million pounds by 1845. This canal also played a significant role in the industrial development of the Mahoning Valley, especially Youngstown, Ohio. It linked Youngstown with the important Brier Hill coal mines, which in 1840 were producing about 700,000 bushels of coal per year. Due to the increasing demand for coal by the growing town of Cleveland, Ohio, on Lake Erie and to the transportation possibilities afforded by the Pennsylvania and Ohio Canal, output at the Brier Hill mines increased to about 2 million bushels annually by 1848 (Scheiber 1969: 215-216; Carlisle and Dalesandry 1988: 2.15-

2.16; Carlisle et al. 1994: 33). By 1830, more than 3,000 miles of canals crisscrossed the United States (Blackford and Kerr 1990: 86).

The widespread construction of canals from the 1820s into the 1850s had significant consequences for urban life. As canals were constructed, prices for imported and native manufactured goods declined and became more affordable to a greater proportion of town residents. Canal warehouse and dock areas became busy loci of urban commercial life. Furthermore, extracted mineral wealth such as coal and iron ore could be shipped or trans-shipped more economically to the rapidly growing population of urban consumers and to a growing number of businesses (Carlisle 1994: 6). At first, canals were not necessarily the cheapest form of transportation (though rates on the canals generally were better than overland rates), but canal transportation often was faster. For example, in 1833 New York goods could be shipped to Nashville, Tennessee, more cheaply by coastal sailing from New York to New Orleans and then by transporting the goods up the Mississippi, Ohio, and Cumberland river on steamboats. The same goods, however, arrived more quickly by sending them on the Erie Canal, across Lake Erie to the Ohio & Erie Canal at Cleveland, Ohio, down that canal to the Ohio River at Portsmouth, then down the Ohio River and up the Cumberland. After 1833, the canal route became even more desirable as rates fell further in comparison to the earlier coastal route. In 1852, businessmen in Cincinnati found it more economical to ship tobacco to New York markets via the Ohio River, the Ohio & Erie Canal, Lake Erie, and Erie Canal route than to send it down the Ohio and Mississippi rivers to New Orleans and up the coast by ship. The tobacco also arrived at its destination in much better condition (Blackford and Kerr 1990: 86).

Railroads

As great an improvement over land transportation as canals proved to be, they were still hampered by ice in winter and by periods of low water in the summer and autumn months. Upkeep on the canal prisms, towpaths, conduits, bridges, and other features was expensive and never-ending. The railroad, in contrast was, for the most part, unhampered by winter weather, was mechanically reliable, faster, and new lines could be laid down relatively quickly to connect any two points. Railroads were developed in England during the early 1800s, and the first American Railroad, the Baltimore & Ohio, was chartered in 1828 to connect, as the name reflects, the growing Maryland metropolis with the Ohio River and the growing markets of the American West. Almost from the beginning of the canal era, then, a new and better form of transportation was on the march and would soon make most of the canals obsolete.

The use of rail to connect a city with a major interior waterway was typical of the early railroad period in this country and acknowledged the importance of the rivers as the dominant avenues of travel and trade. Soon, however, railroad tracks were being laid between inland towns away from the major rivers. At even greater fever pitch than it had been with canals the generation before, boosters in every town now competed with those in every other town for the railroad's patronage and the feeling of importance and "centrality" that being on the rail line conveyed.

The effects of the construction of the first railroad lines were felt far beyond the physical limits of their rails. For example, the Baltimore & Ohio Railroad line was extended to Cumberland, Maryland, from Baltimore in 1844. From that time until the arrival of the railroads in western Pennsylvania in 1852, it was not unusual for perhaps 25 stagecoaches a day, each with nine or more passengers, to leave Wheeling and to pass through Washington, Pennsylvania, en route to Cumberland. Similarly, a like number of passengers would leave Cumberland for Wheeling, traveling through Washington on the National Road.

In addition to the railroads, early river navigation improvements also played an important role in facilitating travel and commerce and had a profound effect on the relative economic fortunes of urban centers. Pittsburgh's boosters and merchants had been deeply worried by the construction of the National Road well south of their town and by the competitive advantage that choice had given to Brownsville and to Wheeling. When the Monongahela Navigation Company completed its slackwater improvements on the Monongahela River as far upstream as Brownsville in the 1850s, however, National Road travelers could leave their stages at that town and travel to Pittsburgh by steamboat. Rail connections at Pittsburgh were available after 1852 and provided additional travel and shipping options for National Road patrons.

The implementation of private navigation improvement measures on the Monongahela River during the 1840s and 1850s and the arrival of the railroad in Pittsburgh in 1852 therefore had a detrimental effect on the National Road traffic west of Brownsville. Long before any major navigation measures were built on the Ohio River itself, much of the mid-nineteenth-century National Road traffic now found it advantageous to complete the Wheeling to Brownsville portion of their trip by water, moving up the Ohio to Pittsburgh and then through the four locks and dams completed on the Monongahela River in 1844 (Gannett Fleming Corddry, and Carpenter, Inc. 1980: 3-4). In 1850, for example, although National Road stages still carried more than 18,000 passengers directly between Wheeling and Brownsville each year, the numbers had been larger in each of the three preceding years. Construction of the first navigation improvements on the lower Monongahela River aided Pittsburgh merchants by allowing them to secure a greater portion of the road's trade.

The railroads were quick to extend their lines into the Middle Ohio River Valley. The early rail lines in Ohio during the 1840s generally ran north to south, connecting the established Great Lakes (and Erie Canal) trade corridor with the older port cities on the Ohio River (Muller 1972: 336, 339). These early railroad lines effectively served the role of connectors to the dominant lake and river transportation system.

This pattern started to change in the early 1850s. Rail lines were extended rapidly to newer interior towns. This trend had a differential effect on the economy and success of towns. In some cases, the rail lines improved the standing of new towns while reinforcing the status of more established towns. In other cases, the lack of a rail line could place even an established town at a serious competitive disadvantage. In 1851, for example, the Columbus and Xenia Railroad connected the river port city of Cincinnati with the interior state capitol at Columbus (located on the National Road). Rail connections could be made at Columbus to reach Cleveland. Cincinnati's established prominence as a river port town was thereby quickly increased by gaining rail access to Lake Erie ports and to the state capitol. By the mid-1850s, Cincinnati had established additional rail connections eastward to Cleveland, Pittsburgh, and Wheeling, and rails also connected the growing city to Lawrenceburg, Madison, Indianapolis, and other western terminals (Muller 1972: 339).

The great period of rail expansion in the Middle Ohio River Valley came between 1850 and 1855 (Figure 3-7). In fact, if anything, the system was overbuilt during this period and established much of the rail pattern seen to the present day. There were 242 miles of rail lines in operation there in 1850. By 1855, more than 12 companies completed an additional 1005 miles of tracks. This represented fully 94 percent of the 1,327 miles of railroad that existed in 1860. Only 80 miles of track were laid down between 1856 and 1860.

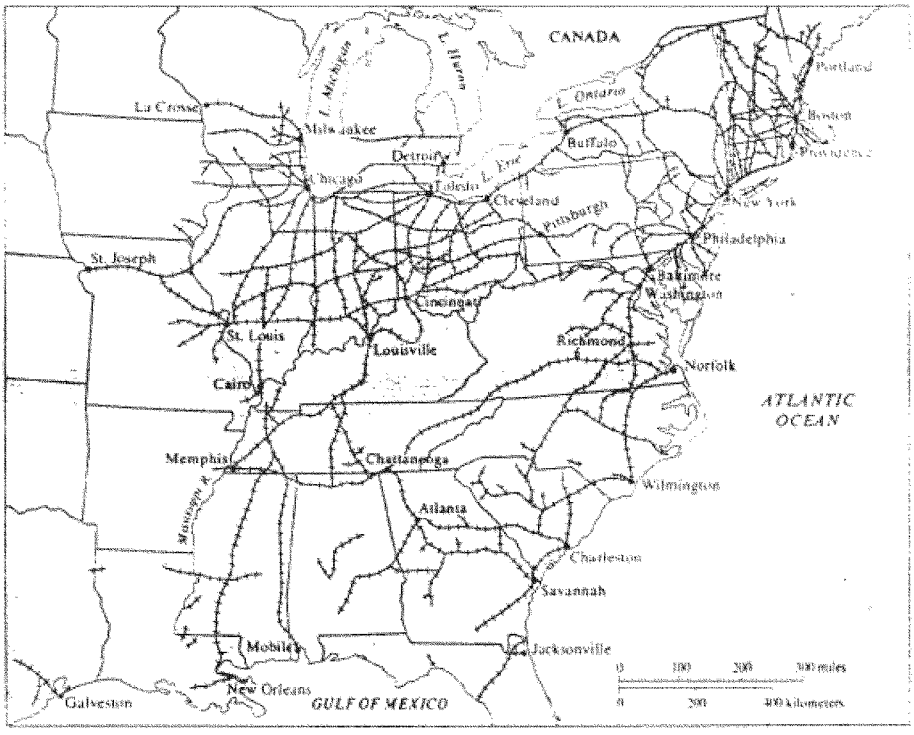

Figure 3-7: The distribution of major railroad lines in the United States in 1860. From Blackford and Kerr (1990: 89).

The rapid expansion of the rail lines in the Middle Ohio River Valley, together with the national economic downturn in the middle 1850s increased competition, caused a sharp drop in freight rates, and reduced the earnings of most rail companies. The drop in rates increased the attractiveness of rail over water transport. The capacity of the railroads to operate year-round also helped to attract a growing trade that traditionally had moved only on the Ohio River. This was especially important during several years in the 1850s when river water levels (either too high or too low) interrupted water-borne commerce. As a result of these and other factors, rail lines increasingly came to dominate the transportation of Upper and Middle Ohio Valley agricultural produce to national markets and the movement in merchandise and manufactured goods moving the other way (Muller 1972: 343). This was a more gradual process than the rapid construction of the railroads in the 1850s might suggest. Steamboat construction in Cincinnati, for example, declined only slightly during the 1850s, and the cheaper cost of water transportation combined with the opening of other markets farther west where the railroad had yet to penetrate meant that the long-term effects of the railroads on river commerce took a while to be fully realized (Muller 1972: 346).

The lack of much additional rail expansion in Ohio by 1860 also meant that cities were largely "stuck" with the network that had evolved quickly during the 1850s. This benefited some Ohio

River cities. Marietta and Belleaire, for example, had three rail connections with the Baltimore & Ohio Railroad on the Ohio River. Wheeling and Parkersburg also enjoyed connections with the B&O. A good deal of the agricultural produce of Ohio now moved east on these lines rather then down the Ohio River to traditional southern markets (Muller 1972: 345-346). Cincinnati, too, was well supplied with rail lines though it now had to compete with inland towns for its share of trade (Muller 1972: 349). However, there was a long stretch of Ohio River between Cincinnati and Portsmouth where there were no rail connections on the eve of the Civil War (see Muller 1972: 341-342). Smaller towns in this stretch had little chance to grow beyond dependence on local commerce and whatever could be brought in or shipped out in the slowly diminishing river trade. Overall, the effect of the railroads on Ohio River towns was beneficial if the town was selected as a railroad through-way or terminal. Even so, the railroads gave increased economic importance to newer inland towns located well away from the river and re-directed the movement of trade. River towns were no longer the only "players" on the urban scene.

Overview of the Development of Major Urban Centers in the Middle and Upper Ohio River Valley

Pittsburgh

Like many other Ohio River towns, Pittsburgh had both a commercial and military component to its origins. The Ohio Company of Virginia began construction of a fortified headquarters at the confluence of the Monongahela and Allegheny rivers in 1754. The purpose was to establish a beachhead in the headwaters of the Ohio River to serve the company's commercial interests in the Ohio River Valley and to provide for its defense. The French and Indian War witnessed the temporary expulsion of the English and Virginians from the area and the construction of Fort Duquesne. Over the next several years after the defeat of the French and Indians in 1758, the English constructed Fort Pitt on the burned-out remains of this earlier fort. Fort Pitt (renamed Fort Dunmore for a time in 1774) remained the most important fortification in the Upper Ohio River Valley throughout the American Revolution. Its military significance declined after the Revolution with the westward movement of the American frontier and the construction of other forts farther down the Ohio River.

Travelers, passengers, and freight were moving actively on the Upper Ohio River long before the improvement of navigation on the river became a reality. In 1787, for example, 120 flatboats passed Pittsburgh on their way down the Ohio, and on one day alone in 1796, 70 flatboats arrived in Pittsburgh from points downstream (Kussart 1937: 16). The trade on the Monongahela River upstream from Pittsburgh also developed in the late eighteenth and nineteenth centuries, and a number of important towns sprang up on that river. One of these, Brownsville, began as another early supply depot for the Ohio Company. Selected in 1818 as the point where the new National Road would cross the Monongahela, Brownsville posed a challenge to Pittsburgh for a time as the center of emerging industry and commerce in the region (see Baldwin 1933, 1938; Carlisle 2000a, 2000b).

In 1803, Pittsburgh business was dominated by iron working and textile production followed by boat-building. Iron products and textiles produced in the town were often marketed via the area's rivers (Reiser 1951: 13, 14). Shortly, glass making became another major industry in early Pittsburgh. The town's first glass factory began as early as 1798. Glasswares also were often marketed by flatboat, keelboat, and later by steamboat to other river towns.

The Monongahela River towns of Brownsville, Elizabeth, and West Elizabeth together with Pittsburgh became the heart of the steamboat-building industry in the Upper Ohio River Valley in

the nineteenth century. In the 1830s some 20,000 people and 4,000 freight wagons annually arrived at Brownsville from the East where they transferred to river craft for the trip downstream to Pittsburgh and beyond. As these and other upstream Monongahela River communities continued to grow during the nineteenth century in population and in the number and diversity of their manufactures and agricultural produce, their residents became avid supporters of river navigation improvements that would enable them to get their products to the evolving downstream population center at Pittsburgh and farther down the Ohio and Mississippi rivers.

The completion of the Pennsylvania Canal to Pittsburgh in November 1829 (with through connections available to Philadelphia by 1834) greatly increased the economic prospects of its merchants and early industrialists. It also increased Pittsburgh's significance as a trans-shipment point for Monongahela River Valley farmers and early industrial producers. Pittsburgh also now could receive many new products from eastern and central Pennsylvania. Iron produced at the furnaces in the central part of the state could be shipped more cost-effectively to Pittsburgh's industrial workshops.

The Pittsburgh wharf master drew up a document in 1840 as a type of survey of potential river traffic that might pass through the locks and dams then being proposed by the Monongahela River Navigation Company. The document showed that in 1839, 686 keelboats loaded with produce and 1,084 flatboats loaded variously with iron, coal, and bricks had used the Monongahela wharf at Pittsburgh. This enumeration did not include the steamboats that were using the river in increasingly large numbers. (Kussart 1937: 15).

In 1841, the Pittsburgh-based Monongahela Navigation Company opened the first of a series of locks and dams on the Monongahela River that greatly facilitated commerce on that river as well as increased trade to towns down the Ohio River. Between 1841 and 1856, the Monongahela River had been slackwatered as far upstream as the towns of Greensboro and New Geneva, both of which soon thereafter developed important stoneware pottery businesses that marketed their wares by river in Pittsburgh and as far south as New Orleans. Soon thereafter, Pittsburgh also became a transportation nexus for rail lines, the Pennsylvania Railroad being only the first to arrive in 1852.

Coal was among the earliest commodities shipped on the Monongahela River, and the coal trade came to dominate the river's commercial traffic, especially from the 1880s through World War I. The Street's Run Creek area along that river was being mined intensively by 1828 to meet Pittsburgh's own demands. The town's population stood at about 30,000 people in 1833 and required some 140,000 tons of coal annually for domestic consumption and perhaps 40,000 additional tons for stores and public buildings. Its 90 steam engines consumed approximately 90,000 tons of coal annually (Binder 1974: 22, 43). Through-shipments of coal down the Ohio River also were important to Pittsburgh's economy even before navigation improvements were introduced on the Monongahela River beginning in 1841. Southwestern Pennsylvania sent bituminous coal to the East Coast via river shipments to New Orleans and then by sailing ship up the coast as early as 1803. Cincinnati, Louisville, Mayville (Kentucky), St. Louis, and New Orleans all were early recipients of bituminous coal from western Pennsylvania, regular shipments of which began about 1817 (DiCiccio 1996: 17). About 5,000 southwestern Pennsylvania men were engaged in bituminous coal mining by 1860 (DiCiccio 1996: 31).

Between 1860 and 1900, the population of Allegheny County, Pennsylvania, which includes Pittsburgh, increased from 179,000 to 775,000 (Couvares 1984: 32, Table 3; 81, Table 4). A large percentage of this growth took place in the city, but the populations of adjacent Monongahela River Valley industrial towns also increased greatly during this period due to the

construction of huge steel plants in Braddock, Duquesne, McKeesport, Monongahela City, Monessen, and other river towns. The Monongahela and its excellent system of locks and dams, the availability of rail connections, and an increasing supply of immigrant urban labor all contributed significantly to the selection of these towns as sites for new plants. The railroads, the rivers, and later in the century, industrial boat fleets on the Great Lakes connected the steel making process together and allowed all of the essential materials to come together at one place. These transportation venues then allowed the finished products to be shipped out at competitive prices.

Between 1841 and 1904, the Monongahela Navigation Company and, after 1897, the U.S. Army Corps of Engineers extended the Monongahela River navigation improvements upriver through the heart of the river valley's rich coal fields to the vicinity of Fairmont, West Virginia. The Monongahela River Valley was transformed by industrial growth along its banks and by access to cheap river transportation into one of the most important and productive industrial river valleys in the world. By 1935, more tonnage was being shipped on Monongahela River than through the Panama Canal, and in 1937, the Monongahela was carrying slightly more tonnage annually than the Ohio River. The great majority of this freight consisted of coal.

Iron and steel started to be shipped on the Monongahela River in World War I as an auxiliary to the rail lines. Increased rail freight rates after the war and a shortage of rail cars led several mills to look to the rivers as a less expensive mode of transportation for some steel products to distant customers. They also began to ship scrap, pig iron, and molds from blast furnace to the mills by river (Tomer 1939: 47).

In 1922, the Carnegie River Service expanded its services and began to tow finished steel products down the Ohio and Mississippi River systems as far as New Orleans and opened its major river terminal near Pittsburgh's major steel plants in 1924. Following the U.S. Army Corps of Engineers' completion of the 9-foot canalization of the Ohio River in 1929, it was possible to ship finished steel products from Pittsburgh down the Ohio and Mississippi to the Carnegie-Illinois Steel Company's warehouse in Texas via the Intercoastal Canal (Tomer 1939: 49). Under a series of ownerships, this river transportation service continued throughout the critical days of World War II ceasing operation in 1985 in the face of the widespread collapse of Pittsburgh's heavy industry (Kudlik 1998: 90-91; Carlisle 2000a, 2000b).

Beaver, East Liverpool, Weirton, Steubenville, and Wheeling

The small town of Beaver, Pennsylvania, is located high on a bluff overlooking the confluence of the Beaver River to the east of the town and the Ohio River on the south. In the eighteenth century, this was about one day's river trip below the Forks of the Ohio. The area was a favored location for settlement well before the permanent arrival of white settlers and the laying out of the town. At least two earlier Indian towns are thought to have been located in this stretch of the Ohio River. The first was located at the present site of Rochester Borough (est. 1849) on the Ohio and the east side of the Beaver River. The names "Logan's Town", "Sawcunk", and "King Beaver's Town" may all refer to the same or successive Indian towns at that location. The Delaware may have been living here by 1725. Conrad Weiser reported visiting the town, which he described as being eight miles below Logstown, in 1748. The second Indian town in the area, "Shingas' Old Town", is thought to have been three-quarters to one mile downstream from the confluence of the Beaver and Ohio rivers. The site was probably settled first by the Shawnee in the 1730s. The French are believed to have constructed some 38 log houses for the Indians at this town, and it became an important early trading center. George Croghan established one of his

trading posts here in 1748. The Indians apparently abandoned the town after the English took the Forks of the Ohio in 1758 (Richardson and Carlisle 1977: 108-109).

Fort McIntosh was built within the present limits of the town of Beaver in 1778. The post was used as a staging ground for an abortive American campaign against British-held Fort Detroit during the Revolution. For a time, it replaced Fort Pitt as the headquarters of the Continental Army's Western Department. An overland road from Pittsburgh led to Fort McIntosh, but troops and supplies often shuttled to and from the post on the Ohio River. The fort was maintained until 1788, when it was torn down and its function replaced with a blockhouse on the Beaver River (Carlisle 1979). Its major importance in the post-Revolutionary period was as the site of the Treaty of Fort McIntosh in 1785.

The town of Beaver is a pleasant and comfortable residential community with a small main street commercial district. Its selection as the county seat of Beaver County (formed in 1800) steered most of the county's law and court activity to the town.

East Liverpool, Ohio, just about mid-way between Pittsburgh and Wheeling on the Ohio River, lies near the center of the Upper Ohio River Valley's historic manufacturing district. Pittsburgh soldier and businessman Isaac Craig purchased the first land that later included the town site of East Liverpool from the federal government in 1797. Craig subsequently sold part of this tract to Thomas Fawcett, an Irishman who then lived on Chartiers Creek south of Pittsburgh. Fawcett's plot, which he called St. Clair Town (but which other early inhabitants usually called Fawcettstown) marked the first settlement at the site of East Liverpool in 1802 (Gates 1984: 5, 8, 10). The town became part of the new state of Ohio, formed in 1803.

Despite a seemingly advantageous initial location on the Ohio River, the town grew slowly at first. It contained only five or six houses in 1807. Between 1802 and 1816, Fawcett managed to sell only 16 of the 117 lots in his town plan even though another of the Fawcetts had erected a tavern and gristmill, and the town had attracted a post office before 1810. Early East Liverpool developed few roads leading inland from the river to connect the fledgling settlement with its agrarian hinterland. It seems likely that early East Liverpool's relatively slow growth also may have been due to a lack of entrepreneurship on Fawcett's part and competition from nearby areas and other early towns on Little Beaver and Little Yellow creeks, both of which were better situated to support water-powered mills. In contrast to East Liverpool the community of Georgetown, on the Ohio River opposite the mouth of Little Yellow Creek, for example, had three mercantile stores, 30 houses, and a post office by 1807 and was recognized as an important stopover for river travelers. East Liverpool also received competition from the town of West Union (Calcutta), established three miles to the north and Wellsville, set up in 1823. In contrast to Fawcett, Wellsville's founder, William Wells, was an aggressive promoter and actively sought the construction of new roads to his town. Consequently, Wellsville rather than East Liverpool attracted new stage and mail routes and became a transfer point for steamboats headed to and from Pittsburgh in the late 1820s (Gates 1984: 10-15). In such ways could one town gain ascendancy over its competitors.

A name change from Fawcettstown to Liverpool in 1816 marked the transfer of ownership of unsold lots in the town from Thomas Fawcett to a consortium of buyers that included his son, John. The new owners promoted the town more actively, sold lots at public auction, built a warehouse near the Ohio, a school, and increased the width of the town's streets from 50 to 60 feet. The group sold the remaining lots in the town to Claiborne Simms in 1825. In only seven years, Simms had sold off 101 lots in the town and had added an addition. The town was incorporated as East Liverpool in 1834.

The town's growth in the 1830s was tied directly to the development of roads connecting it with the hinterland and to the development of river shipping for agricultural produce and industrial goods produced in the rest of Columbiana County. The prospects for construction of nearby canals and a railroad (the Ashtabula, Warren, and Liverpool) also boosted enthusiasm for the town as did the creation of Liverpool Township in 1834, of which East Liverpool was the only sizable urban center. East Liverpool's population rose from a mere 136 in 1830 to 503 in 1840. The population was relatively young, too. Forty-nine percent of its residents were in the prime working years between 15 and 50 years of age. The economy also had diversified and matured. Only 12 East Liverpool citizens were engaged in agriculture in 1840; 80 were employed in manufacturing; 12 others in commerce; 14 in river, canal or lake navigation; and three in "learned professions" (Gates 1984: 18-27).

East Liverpool's claim to fame as one of the country's premier producers of ceramics began in 1839 (Figure 3-8). It was predicated on the growing domestic market for locally produced household wares and storage vessels, the availability of high-quality clays, and the presence of the Ohio River used to transport the ceramics to both local and more distant markets. English potter James Bennett fired his first earthenware in East Liverpool in 1840. His three brothers joined him from England in 1841, and the Bennett Brothers Pottery produced both yellow earthenware ceramics and a manganese-mottled form of the pottery, known as "Rockingham." The Bennett Brothers' commercially produced wares were being advertised in Pittsburgh newspapers in 1841 and also were sold through Cleveland, Cincinnati, Louisville, and St. Louis

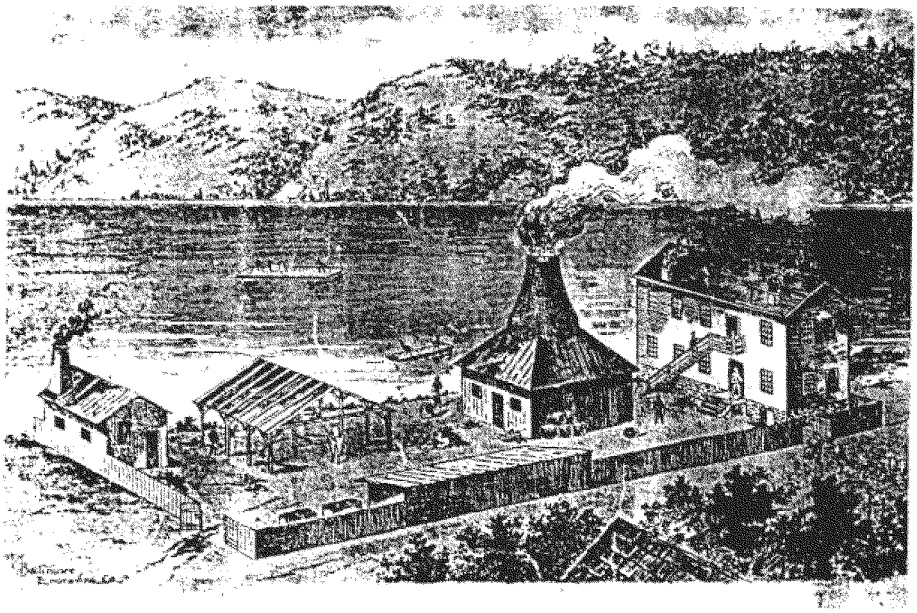

Figure 3-8: An artist's rendering of what an early pottery in East Liverpool, Ohio, might have looked like ca. 1840. From Gates (1984: 30).

merchants. Although the Bennetts were successful in East Liverpool, they moved their pottery operation up the Ohio River to Pittsburgh in 1844, to take advantage of better access to fuel (Gates 1984: 32) and, presumably, to the enhanced transportation facilities that came with the opening of the Monongahela Navigation Company's locks and dams on the Monongahela River.

The Bennetts' success in East Liverpool attracted many other potters, and the increased business made the once lackluster town "...very agreeable and prosperous..." by 1850 (Gates and Ormerod 1982: 3-4). In 1853, 11 potteries were operating in the town that employed 387 people and turned out $175,000 worth of ceramics annually. The largest producer in the town at that time was the Phoenix Pottery. The pottery complex consisted of five buildings and three kilns and employed 40 people (Gates and Ormerod 1982: 4). Before 1852, East Liverpool pottery was marketed almost exclusively via river transportation. Completion of the Cleveland and Pittsburgh Railroad to nearby Wellsville in 1852 and extension of the line to East Liverpool itself in 1856 significantly boosted the town's commercial pottery industry by offering new trade routes directly to the new inland towns that were growing up along the tracks. East Liverpool ceramics were being sold in Chicago, for example, by 1857, as well as in the New Orleans market.

In 1877, there were 23 potteries in East Liverpool, and the ceramic industry dominated employment in the town. Prosperity peaked between 1880 and 1930 when the traditional yellow ware and Rockingham wares were supplemented by newer white earthenwares. Production of this additional ceramic line required the importation of new and different clay types from Missouri, Texas, Georgia, and as far away as England. This was made economically feasible primarily by the excellent rail connections that the town enjoyed. The period also witnessed the adoption of more modern ceramic-making technology, mechanization, and mass production. Growth of the ceramic industry also led to specialization of production and the rise of support businesses within the town. Clay preparation, ceramic decorating, and ceramic design could be "farmed out" to smaller companies. By 1877 the firm of Knowles, Taylor and Knowles was using natural gas to heat its kilns. East Liverpool supplanted Trenton, New Jersey, as the country's leading producer of dinner wares and ceramic toilets by 1895. Town population swelled with the success of the ceramic industry: 2,105 people in 1870 to more than 20,000 by 1910. Seven thousand people were employed in the town's ceramics industry in 1930 (Gates and Ormerod 1982: 3-6).

The twentieth century also witnessed changes in the ways in which ceramics were marketed. Mail order catalogs and wholesale ceramic merchants were used. Department stores now offered the wares through their own outlets. Plates, cups, saucers, and other wares were also given away to housewives as "free" premiums with the purchase of everything from movie tickets to newspaper subscriptions. Annual ceramic production in East Liverpool was valued at $25,000,000 in 1923 (Gates and Ormerod 1982: 5-7).

Although the growth of the ceramic industry contributed greatly to East Liverpool's fame and success as a town, the requirements of the growing industry had begun to outstrip the available space as early as 1900. Hemmed in by the Ohio River and other geographic barriers, the growing potteries began to look for space outside the town. This contributed to the establishment and growth of nearby towns even as it began to sap East Liverpool's vitality Chester, West Virginia, opposite East Liverpool on the Ohio, became the site of the Taylor, Lee, and Smith pottery and later of the Edwin M. Knowles China Company, and the Harker Pottery Company. Other potteries were started in Newell, West Virginia, Wellsville, and Salineville, Salem, East Palestine, and Sebring, Ohio. By 1940, only six dinnerware potteries and a few other manufacturers of ceramic products remained in the East Liverpool area. Mismanagement, foreign competition, and the Great Depression of the 1930s also contributed to the downturn in East Liverpool's ceramic

industry and with it, the economic fortunes of the town. Still, a few East Liverpool potteries held on, modernized, and introduced new lines of products into the 1960s (Gates and Ormerod 1982: 6-7). From the 1950s onward, however, trends in both the local and national pottery industry have continued to decline (Gates 1984: 313-407). The condition of homes, the business climate, and the civic infrastructure of East Liverpool have tended to mirror all of these larger and mostly negative trends.

Steubenville, Ohio, is 20 miles below East Liverpool on the Ohio River and was established in 1798. The flood tide of immigrants pouring into the Northwest Territory at this time soon swelled its population, which had a large German component. The establishment of a federal land office in the town in 1800 also helped to attract new residents, visitors, and those purchasing lands in other parts of Ohio. The needs of this rapidly expanding western population contributed to Steubenville's early industrial and commercial development. The young town soon boasted a woolen mill, iron foundry, several potteries, brewery, paper mill, steam-powered flour and cloth mills, and a tobacco/cigar factory. Town artisans also turned out a host of consumer goods suitable for sale to local residents and to settlers moving down the Ohio into the Ohio and Kentucky frontiers. These goods included such necessities as shoes, clocks, guns, wagons, and hats. Most of these products and the people who purchased them traveled down the river on flatboats, keelboats and, later, steamboats. The down-river traffic included mainly agrarian produce and manufactured items, but cotton, fur, tobacco, and hemp also moved upriver from Kentucky. Steubenville's population grew rapidly in these exuberant times. It stood over 2,000 in 1818 and 3,000 in 1830. Among contemporary Ohio towns, only the populations of Cincinnati and Zanesville were larger (Gates 1984: 7; Roseboom and Weisenburger 1986: 64, 112). Steubenville (as well as Gallipolis, Portsmouth, Ironton, and Ripley) also developed a small industry in the construction of steamboats. The production was not as large as that in Wheeling or Marietta. The latter had developed substantial boat construction businesses, though much smaller than the major steamboat-building centers that evolved near Pittsburgh and up the Monongahela River at towns such as Elizabeth, West Elizabeth, Brownsville, and California, Pennsylvania (Hunter 1949: 107).

Late in the nineteenth century, historian Reuben Gold Thwaites found that Steubenville's population had grown to about 16,000, and like many river towns, presented a wide, impressive stone-paved wharf to visitors arriving by boat. Some of the town's residents were disturbed by the fall-off in steamboat traffic, but just three miles down the Ohio a large iron and steel plant at Mingo Junction created many new industrial laboring jobs filled by Eastern European immigrants, a situation that Thwaites feared was "...fast degrading legitimate American labor" (Thwaites 1999: 45). In addition to steel, the Steubenville area's traditional industrial base also has included coal, as well as glass and tin manufacturing (Klein 1968: 37).

Next to Pittsburgh, Wheeling became the most important town on the Upper Ohio River at an early date. Numerous pioneers pushed into the Ohio River Valley between 1772 and 1777 coming either down the Ohio River via Pittsburgh or up the Shenandoah Valley of Virginia, across the Blue Ridge and down the Kanawha, Big Sandy and Kentucky River drainages. The earliest settlement at Wheeling is usually attributed to Ebenezer, Silas and Jonathan Zane about 1769; however, George Washington made no mention of any settlement there on his 1770 tour through the Ohio River Valley in search of good lands. Ebenezer Zane, David Shepherd, John Wetzel, and Samuel McCulloch, all early settlers in the Wheeling area, later maintained that their initial settlement there began in 1772.

Two years later, Major William Crawford erected Fort Fincastle at the future site of Wheeling, where Colonel Angus McDonald raised a force of about 400 men for an expedition against the

Shawnee during Dunmore's War of 1774 (Rice and Brown 1993: 29, 33). This was one of a number of frontier fortifications designed to protect the early settlers of the Ohio Valley. It was an important rallying center for George Rogers Clark's planned expedition against the British at Fort Detroit in 1781, and the post was attacked by the Indians in September of the following year (Rice 1970: 67, 82, 110, 116). In 1785 or before, Isaac Zane and George Green developed a cattle trade between Wheeling and Detroit. Cattle were exchanged for skins and furs. Indians killed both men, however, on a later trip (Rice 1970: 158).

In the early nineteenth century, Wheeling developed as a place where settlers moving down the Ohio could acquire provisions. The river between Pittsburgh and Wheeling hosted many floating stores and vendors of all sorts. Small but useful manufactured goods could be exchanged or bartered for agricultural produce. Together with Point Pleasant and Cedar Grove (on the Kanawha River) boat building became an economic focus in Wheeling at an early date (Rice 1972: 112). In 1816, the 403-ton steamboat *Washington* was built at Wheeling and made a round-trip to New Orleans from Wheeling and back up to Louisville in just 41 days (Rice 1972: 117). The boat managed to chug up the Mississippi and Ohio system from New Orleans to Louisville in 25 days (Rice 1970: 320). This was one of the first indications of the utility of steam-powered navigation on inland waters. Before long, the trip from New Orleans to Louisville was cut to five days (Rice 1972: 117).

Wheeling's evolution in the nineteenth century was marked by economic growth and diversification, the emergence of industry, and by attendant progress in health care and education. Several early physicians took up residence in Wheeling, including one in 1808 who came with a medical degree from the University of Pennsylvania. Another graduate of this institution arrived in 1819 (Rice 1970: 201, 202).

The first newspaper was published in Wheeling in 1807, 21 years after the first newspaper had been published in Pittsburgh (Rice 1970: 262). The Wheeling Lancastrian Academy was established in 1814 (Rice 1970: 237), and in the 1820s the town was an important site for early textbook publishing as well (Rice 1970: 265). In 1849, the Wheeling area became the first independent school district in Virginia (Rice 1970: 232). An attempt to start a university at Wheeling occurred in the spring of 1831, but the initiative failed to win the support of the state legislature. Before 1840, Wheeling (and Wellsburg) were among other Virginia towns that had developed literary or library associations to promote education (Rice 1970: 259).

These educational endeavors grew out of the town's increasingly important status as a center of trade and commerce poised at the crossing of the National Road over the Ohio River. In 1810, Wheeling was a village of only 120 houses and 11 stores. By 1820, two years after the National Road had reached the town from Cumberland, Maryland, Wheeling was Virginia's second most populous town after Richmond. In 1830, it was the most populous town in northwestern Virginia (Rice 1970: 255, 334). It was estimated that 4,681 wagons, each averaging about 3,500 pounds, were unloaded in Wheeling in 1822 as a result of the presence of the National Road. The cost of transporting this merchandise to Wheeling from Baltimore was calculated at $390,000. These figures did not include wagons that merely passed through Wheeling, perhaps another 468 wagons or 10 percent of the larger figure (Rice 1970: 334).

Wheeling became an industrial center before the Civil War even though the development of its banking institutions lagged significantly behind the development of that crucial business in Pittsburgh and Washington, Pennsylvania, and Marietta, Zanesville, and Steubenville, Ohio. Since the early nineteenth century there had been a branch of the Bank of Pennsylvania in Pittsburgh. In contrast, there were still no state-chartered banks in Wheeling in 1815 (though a

private bank had organized there the year before). Businessmen in western Virginia complained that banks in the eastern part of the state would not make them loans due to the great distance and the poor transportation facilities connecting eastern and western Virginia (Rice 1970: 317, 318, 320, 322; 325-327). Thus, despite the fact that Wheeling and Pittsburgh were industrial competitors, many businessmen in Wheeling had to look to the capital available in Pittsburgh to fund their ventures (Rice 1970: 326-327). Even in the early nineteenth century, one perhaps can see the beginnings of the metropolitanism that allowed Pittsburgh to exert its influence as the major city of the Upper Ohio River Valley, an influence that has remained to the present time (see Muller 1989). The pleas of western Virginia businesses were answered in 1817 with the establishment of the Northwestern Bank of Virginia at Wheeling. The bank was authorized to establish branches at Clarksburg, Morgantown, and Wellsburg and was capitalized at not less than $400,000.

The Wheeling Iron Works was turning out about 1,000 tons of iron annually in 1835. Most of this output was nails (leading Wheeling to be called the "Nail City"), about 300 tons, but bar, sheet, hoop iron, and boiler iron also were produced. Four foundries and four steam engine factories in the town employed about 140 workmen. The Wheeling Manufacturing Company produced steam engines and other iron products. Coal from the West Virginia Northern Panhandle often fueled the Wheeling industries. In the 1830s, the town had foundries, steam engine factories, flour mills, glass houses, distilleries, cotton and wool factories, paper mills, and sawmills that used up perhaps 1,000,000 bushels of coal each year (Rice 1970: 315, 316). Good sources of clay, coal and wood for fuel, and access to the river for the transportation of the finished products made the Wheeling-Wellsburg area an ideal location for early pottery and glass production. Wellsburg was the earlier glass-making center, but Wheeling's location on the National Road attracted the attention of that industry in the 1820s. In 1820 or 1821, an eight-pot glass factory was in operation in Wheeling, begun by George Carothers who came from Brownsville, Pennsylvania, on the Monongahela River. The business was short-lived, however. John and Craig Ritchie opened a more successful flint glass plant in Wheeling in 1829 and put sevral other plants into operation a few years later. By 1835, there were five glasshouses and two glass cutting businesses in operation in Wheeling that employed 193 men (Rice 1970: 317). Potteries were working at Wellsburg by 1805, and Wheeling had two major potteries in operation by 1814. The large number of landless working men attracted to the town's industries also made Wheeling the focus of the first important labor movement in what is now West Virginia in 1829 (Rice 1970: 325). Wheeling also has been a center of pottery-making in more recent years together with Ravenswood, Huntington, and Parkersburg, all on the Ohio River (Rice 1972: 268).

Both Wheeling and Wellsburg were important milling centers on the Upper Ohio River. Wellsburg shipped 30,000 to 40,000 barrels of flour down the Ohio and Mississippi rivers to New Orleans each year, and Wheeling then had three steam-powered gristmills in operation. Fulling and carding mills were significant in Wellsburg, which also had rug and cotton factories (Rice 1970: 322). Wheeling eventually became known as a center for the manufacture of calicoes (Rice 1972: 268).

All of the products of the Wheeling industries and businesses discussed above had to be shipped either overland via the National Road (after 1818) or were marketed by loading them onto flatboats, keelboats, or, later, steamboats for distribution via the Ohio River.

Several new transportation improvements at Wheeling about the middle of the nineteenth century gave that town a shot in the arm in its economic competition with Pittsburgh. An engineering marvel of its day, and the first of its kind in the country, was the construction of the Wheeling Suspension Bridge over the Ohio River, which opened in 1849 (Rice 1972: 138). This was

followed by the arrival of the first railroad to reach western Virginia, the Baltimore & Ohio (B&O). This railroad reached Wheeling on New Year's Day in 1853 and provided a direct link to Cumberland and Baltimore.

When West Virginia became the thirty-fifth state in 1863, the first capital was located at Wheeling to place it safely within Union lines during the Civil War. In 1870, however, Charleston, an inland town on the C&O Railroad line then under construction was selected as the capital. However, Wheeling constructed a large building that it offered to the state as a capitol, and the seat of government therefore was moved back to Wheeling in 1875. A state referendum in 1877 selected Charleston, however, and in 1885 the capital of the state was again moved to Charleston. On the occasion of each move, all the state records were moved by steamboat (Rice 1972: 206, 215-216).

In the industrial era of the later nineteenth and most of the twentieth centuries Wheeling and Weirton were part of the national heavy industry heartland in the Upper Ohio River Valley. The center of this heartland was at Pittsburgh until the collapse of that industry between roughly 1960 and 1980. By the late nineteenth century, electricity was becoming indispensable for industrial production. The first electric light plant in West Virginia was opened at Wheeling in 1882 (Rice 1972: 265). Weirton Steel Company, however, opened a "Steel Mill of the Future" in the early 1970s, and Wheeling-Pittsburgh Steel Company, although beset with recurrent financial problems, has become a leader in the field of tin plate products. The steel industries in both Weirton and Wheeling utilized shipping on the Ohio River and developed significant markets in the lower South (Rice 1972: 263). In 1968, four Ohio River metals plants—Weirton Steel, Wheeling Steel (now Wheeling-Pittsburgh), International Nickel Company at Huntington, and the Kaiser Aluminum plant at Ravenswood employed over 2,000 workers each (Rice 1972: 263).

Marietta

Fort Harmar, located at the confluence of the Ohio and Muskingum rivers, originally was established to interdict boatloads of squatters heading downstream into the Ohio country. The community of Marietta, Ohio, first called Adelphia or Adelphi, the first legal settlement on the Ohio side of the river, was started by the Ohio Company of Associates (often called the "second" Ohio Company) in the spring of 1788. Most early settlers at Marietta were New Englanders. The residential architecture of the town to this day reflects this origin. A number had been educated at Harvard or Yale and formed a contrast with most frontiersmen. A good number of the early men of Marietta also had served in the Revolution, and they supported law, order, and the operation of fraternal organizations in their town, such as the Society of the Cincinnati and the Masons. The arrival of Arthur St. Clair, the first governor of the Northwest Territory in July 1788 also increased Marietta's prominence as a recognized seat of political and military power (Roseboom and Weisenburger 1986: 54, 62). The active promotion of new settlement by the Ohio Company of Associates soon resulted in the establishment of additional communities, including Belpre (a contraction for *belle-prairie*), 12 miles down the Ohio from Marietta, in April 1789 as well as other settlements up the Muskingum River at Waterford, Plainfield, and Big Bottom (Bond 1941: 287; Carlisle and Michael 1981: 26-27). The Big Bottom settlement was attacked by the Wyandots and Delawares on January 2, 1791, and 12 settlers were killed.

Washington County, containing Marietta, was the first Ohio County to be set up (in 1788) in the tumultuous days after the establishment of the Northwest Territory. Belpre Township came into being on December 20, 1790. The town of Belpre was separated into an "upper" and "middle" settlement by a large soil bank, known historically as "the Bluff." The rich agricultural soil naturally resulted in farming as the mainstay of Belpre's economy in the nineteenth century

(Andrews 1902: 296-297). Most of the early improvements in this area consisted of grist and saw mills, orchards, vinegar mills, and other agriculturally related endeavors (Washington County Historical Society 1980).

The constant threat of Indian attack led many early homes in Belpre to do double duty as residences and as blockhouses. Colonel Battelle's and Colonel Cushing's residences formed two such structures within a tightly knit cluster of 13 log buildings at the Belpre settlement that was known as "Farmer's Castle." This was on the north shore of the Ohio River approximately opposite the middle of Blennerhassett Island. In addition to Fort Harmar (at Marietta) and Campus Martius, the fortified settlement erected by the Ohio Company of Associates at that town, Farmer's Castle presented one of the most secure and imposing appearances on the American frontier in 1790 (H. Z. Williams and Brother 1881: 509-510).

Another frontier fortification, Nye's Fort, was built in 1792 on the Ohio side of the Ohio River opposite the southern end of Washington Bottom and Newbury Island or Newbury Bar. This fort protected settlers in the "Lower Settlement," also called the Newbury Settlement, southwest of Belpre and south of the Little Hocking River, who were too far from the protection of Farmer's Castle. Newbury Island in the Ohio River is a linguistic reminder of this early Ohio River settlement. The name "Newbury" also reflects the New England origins of many of the early settlers who came to the Parkersburg/Belpre area by way of Marietta, Ohio. Newbury is derived from Newburyport, Massachusetts, the home of Nathaniel Sawyer. Sawyer arrived in Marietta in 1789 and built the first home near the mouth of the Little Hocking River in 1796 (Preston 1909: 4).

In 1800, William Henry Harrison and Albert Gallatin succeeded in getting new federal legislation passed that dropped the minimum amount of land a person could purchase in Ohio from 640 to 320 acres and extended credit for four years. Reinforcing the importance of early towns in Ohio, the act also opened land offices at Marietta, Cincinnati, Chillicothe, and Steubenville. The resulting inflow of new settlers soon paved the way for a movement to admit Ohio to the Union (Roseboom and Weisenburger 1986: 64).

Marietta, Pittsburgh, and Wheeling all became major ship-building centers on the Ohio River early in the nineteenth century. Sailing schooners were constructed for the down-river trade to New Orleans, but most of these ships then took to coastal sailing rather than hazarding the return up the Mississippi and Ohio River system. In 1807, some 1,800 boats went down the river to New Orleans, but only 11 came back up. British interruption of the Atlantic sailing trade during the War of 1812 caused American merchants to turn to the interior river systems, and numbers of southern keelboats were arriving in Pittsburgh and other Ohio River towns by 1815. Together with Pittsburgh, Brownsville (on the Monongahela River), and Cincinnati, Marietta became a leading manufacturer of flatboats and keelboats in the era before steamboats controlled the river trade (Wade 1959: 40).

By 1810, newspapers were being published in Marietta, which joined Cincinnati, Chillicothe, Steubenville, and other Ohio towns.. Sixty newspapers were being published in Ohio's towns by 1826. Building on the respect for education that Marietta's first settlers brought with them. the decade between 1830 and 1840 saw the establishment of the school that grew into Marietta College. In subsequent years, Marietta developed an economy based on varied manufacturing, and both wholesale and retail trade. Its population had grown to about 17,000 by the late 1940s (Banta 1949: 537). Today, it is a rather sleepy but beautiful Ohio River town that gives the casual visitor little sense of its earlier importance in the history of the Ohio River Valley.

Parkersburg

One of the most important towns on the Ohio River between Pittsburgh and Cincinnati is Parkersburg, West Virginia, located on the south bank of the river at its confluence with the Little Kanawha River. The first tentative settlements at Parkersburg occurred in 1773 when Robert Thornton, Vallentine Cooper, Benjamin Harding, and James Neal arrived at the mouth of the Little Kanawha. A number of other settlers spread out along the nearby tributaries of the Little Kanawha but were soon driven out by Indian raids that began in 1774.

Thornton sold his original land holdings to Captain Alexander Parker of Pennsylvania in 1783 for $50.00 (Inslee and Kaltenecker 1949: 5). Although the later town was named for him Parker never lived there. He died in Pennsylvania in 1791 at the age of 38 (Dawson and Null 1969: 2; West Augusta Genealogical and Historical Society 1980: 5).

John Stokely was the next to settle on the Parkersburg side of the Little Kanawha. The area about the mouth of the Little Kanawha became known as "the Point," not to be confused with ground of the same name at Marietta, Ohio, at the junction of the Muskingum and Ohio rivers. Stokely laid out a small community containing 6-8 small houses, a church, school, and store on both sides of that river that he called Newport or Stokelyville (Bartlett 1903: 3; Dawson and Null 1969: 2; West Augusta Genealogical and Historical Society 1980: 5).

The name of Parkersburg was adopted after 1810, when Parker's daughter, Mary Parker Robinson, obtained title to the land. Her husband, William Robinson, was from Pittsburgh, where his family was among the earliest settlers on the north side of the Allegheny River. Robinson laid out the town of Parkersburg in 1811 into a series of lots with streets running both parallel and perpendicular to the Ohio River (Inslee and Kaltenecker 1949: 13).

On the north or Parkersburg side of the Little Kanawha, Captain James O'Neal (later Neal) became the first surveyor and permanent settler. Neal was originally from Springhill Township in Fayette County, Pennsylvania, and was a Revolutionary War veteran. Neal first explored the area about the Little Kanawha in 1772, and he returned in 1783 to survey property Parker had acquired. In 1785, Neal established Neal's Station (or Fort Neal) and acquired title to several thousands of acres on the south side of the river. The settlement was threatened several times and attacked in 1791 (Withers 1895: 400; West Augusta Genealogical and Historical Society 1980: 5-6).

Before the discovery of oil at the Burning Springs field on the Little Kanawha River about 40 miles up the Little Kanawha River, Parkersburg and the community of Belpre across the Ohio River developed population slowly as the local market towns and redistribution points for regional agricultural produce and livestock. Parkersburg's population in 1820 stood at only 400 and by 1850 had increased to only 1,218.

The economic orientation of this commercial town began to change with the extension of connections with the Baltimore & Ohio Railroad to Parkersburg in 1857 and the discovery of oil at Burning Springs in 1859-60. Parkersburg soon became a major storage and refinery center for oil, which was either carted or floated down the Little Kanawha River to the Ohio River from Burning Springs. Parkersburg's significance as an oil storage, refining, and shipping point and as a railroad center also made it an important area of Union defense during the Civil War.

After the Civil War, Parkersburg's once independent refineries and oil companies eventually were acquired by John D. Rockefeller's Standard Oil Company conglomerate, largely through the efforts of Parkersburg's most famous oil man, J. N. Camden.

The local oil industry required a great deal of lumber for barrels, derricks, and boats; thus, Parkersburg also became a prominent site of sawmills and lumber mills. The mills, as well as tanneries, usually were found along both banks of the lower Little Kanawha River, where both water and water transportation were close at hand.

Parkersburg's population was increased by the influx of oil speculators and workmen. The city's boundaries soon expanded outward and its economic basis became grounded in the increasing industrialization of the nation as a whole. Oil, and later natural gas, remained major economic pursuits in Parkersburg until the city's last refinery closed in 1937, but other industries, specifically wood products, iron and steel, brick making, and to a smaller extent pottery, silk making, and castings continued to contribute substantially to the economic life of the town.

On the opposite side of the Ohio River, Belpre also participated in the economic growth that Parkersburg enjoyed during the nineteenth and early twentieth centuries, though to a more limited extent. Many Parkersburg businessmen originally came from families on the north side of the Ohio, but Belpre retained a more rural and agricultural orientation, and its population remained well below that of Parkersburg. The links between the two towns were first improved by the operation of river ferries across the Ohio River and by the completion of the B & O Railroad Bridge across the Ohio in 1871.

The wealth generated by the oil, timber, and metal industries and the resulting population growth led Parkersburg to expand outward from its original epicenter at the confluence of the Little Kanawha and Ohio rivers. Some architecturally impressive homes and blocks of worker housing were built in the Beechwood, North Parkersburg, and Riverside neighborhoods north of the older city. City parks, rural cemeteries, and some recreational areas such as Terrapin Park, were also erected. Inter-urban trolley lines developed to serve these new suburbs and to tie them to Parkersburg. By the beginning of the twentieth century inter-urban lines also provided transportation connections between Parkersburg and towns such as Vienna and Marietta.

The Little Kanawha River separated Parkersburg from its neighborhoods of Tavennerville, South Parkersburg, and Lauckport south of the river. A bridge over the Little Kanawha joined these areas in 1858 but was destroyed by floods. River ferries therefore continued to provide transportation for many years. Physical separation reinforced political separation; South Parkersburg did not officially become part of Parkersburg until 1950.

Parkersburg was fully integrated with American urban industrialization in the second half of the nineteenth century, but a short distance outside the city one re-entered the earlier agrarian world of subsistence and commercial farming. Family farms continued to dominate Washington Bottom until after the Second World War, for example, and provided many Parkersburg markets with produce and dairy products year-round. Few of the amenities and innovations of Parkersburg's industrial expansion extended even as far as Washington Bottom. Parkersburg received electrical service in 1896, for example, but the farmers of Washington Bottom were still without any regular electrical service as late as 1935. Similarly, the major road across the bottom remained unpaved until industrial growth there by the Dupont, Borg-Warner, Carborundum, and other companies after the Second World War demanded it. These companies, and the development of the petrochemical and synthetics industries provided thousands of new jobs for area residents during the boom years of the 1950s and later.

Parkersburg's population began to decline with the advent of inter-urban transportation about the beginning of the twentieth century and with the spread of the automobile in the 1920s and 1930s, both of which allowed daily long-distance commuting to work and fostered the development of suburban living. Today, Parkersburg is part of the Parkersburg-Marietta Metropolitan Area, and as of 1989 it ranked 221st among 320 MPOs in the nation based on population (West Virginia University, Center for Economic Research 1991).

Huntington

The earliest evidence of settlement at the location of the current Ohio River city of Huntington, West Virginia, came on December 15, 1772 when John Savage and 60 other men received land grants for service in the French & Indian War. Savage's grant included the site of Huntington. A trade in bearskins soon occupied the area around the mouth of the Guyandotte River. A small village called Guyandotte served as a local trading center. By 1800, there was a ferry across the Ohio and one across the Guyandotte River at this village, which did not merged with Huntington until 1911.

Richard and Benjamin Brown laid out a town on tract 37 of the Savage grant. Originally called Brownsville, the town was equipped with an excellent river landing and land transportation route. The "Jeems" and Kanawha Turnpike connected the area with eastern Virginia. The new town was incorporated in 1831-1832. No lots were sold, however, and Brownsville remained a town in name only for four decades (Wallace 1947: 8-11).

In 1869, Collis P. Huntington, who had made money during the California gold rush, was elected president of the Chesapeake & Ohio Railroad. Huntington also had helped to finance the Central Pacific Railroad. He pictured the erection of a town on the Ohio at the junction with the Guyandotte River and the completion of a bridge over the Ohio. At the time, there was no railroad in the state south of the Little Kanawha River, so construction of the C&O was vital to the progress and development of the area. Based on Mr. Huntington's progress over the next two years, the Virginia legislature incorporated the town of Huntington in 1871. Construction of the railroad was carried out from both ends, and the track was completed at the end of January 1873 providing the new town with rail connections via Charleston to Richmond (Wallace 1947: 67-86). A freight and passenger station built at the river dock on Ninth Street in Huntington facilitated transfers of passengers and freight to and from river steamers. An incline was used to move the freight between these two modes of transportation.

Once the C&O rail line was extended to Cincinnati river passenger traffic, especially, began to decline (Wallace 1947: 111). Construction of the Ohio River locks and dams, however, had a beneficial effect on river freight traffic at Huntington. Lock and Dam No. 28 at Huntington was constructed between 1911 and 1915, and the Gallipolis Lock and Dam was built about 32 miles above Huntington; it opened in August 1937.

After the completion of the Ohio River navigation system, the port of Huntington alone contributed waterborne freight in the amount of 3,892,139 tons in 1942, 3,964,377 tons in 1943, and 4,045,102 tons in 1944 (Wallace 1947: 113). These amounts can be compared with freight totals carried on the entire Ohio River system of 18,000,000 tons in 1934, 38,000,000 tons during the early war year of 1942 and 37,000,000 tons in 1944 (Wallace 1947: 113).

Huntington became an important switching point for transfers between river and rail. In the late 1940s, there were 13 river terminals in the short distance of 1.7 river miles at Huntington. These

included no fewer than six petroleum terminals, three coal terminals, two sand and gravel terminals, a marine repair terminal, and one terminal that handled miscellaneous river freight (Wallace 1947: 113).

Huntington is an excellent example of a town where a river confluence, a major road, and excellent river wharf possibilities were insufficient to make the town "happen." The railroad and the town development and jobs associated with that were required. In time, other rail lines were completed to the town providing connections to Cincinnati and other towns and cities. Eventually, passenger service on the C&O was available through Huntington connecting Louisville and Cincinnati on the west with Washington D.C. and Richmond on the east. The Cincinnati Division of the C&O opened on New Year's day, 1889. Through acquisition of another railroad, a connection to Louisville was established in February 1892 (Wallace 1947: 89-90). By 1887-1888 the Baltimore & Ohio (B&O) line also served the Huntington Area through a connection with the C&O via Wheeling Parkersburg and Point Pleasant. Thus by the late 1880s, the Ohio River was paralleled by railroad tracks all along the distance from Steubenville to Cincinnati, Ohio and continuing on to Aurora, Indiana (Wallace 1947: 109). Huntington profited from its position at the junction of both the C&O and the B&O.

When the railroad was started, Collis P. Huntington did not even consider coal to be a potentially major source of revenue for his new line since the West Virginia industry was then in its infancy. There were coal mines in operation at present Montgomery, Loup Creek, Paint Creek, and Coalburg. The Coalburg, West Virginia, mine was in operation before the Civil War. Before the advent of the railroad, the mine shipped its coal on the Kanawha River. Collis Huntington reckoned that Virginia iron ore would be the major freight for the new line at the time. By 1900, however, West Virginia mining had developed to the extent that coal headed for the Virginia Tidewater was the major freight carried on the C&O. Between 1902 and 1945, the amount of West Virginia coal the C&O carried increased from 4,164,260 tons produced at 105 mines to 44,488,630 tons produced by 280 mines The C&O also became a partner in the C&O Steamship Company, which operated a fleet of seven trans-Atlantic steamships out of Newport News, all of which were supplied with West Virginia coal carried on the C&O line (Wallace 1947: 88, 90, 92). The C&O's Newport News terminal covered over 1,000 acres in the late 1940s and had a water frontage of 8,000 feet. There were two electrically operated coal piers, one of which was 1,200 feet in length and capable of loading four large vessels simultaneously (Wallace 1947: 104). In 1945, the railroad operated 1,708 miles on its main line, 1,736 miles on branch lines, and had sidings, second and third tracks, etc. besides, in all 6,192 miles of track. Moreover, the line had been profitable every year since 1889. Passenger service was operated and daily service each way between Cincinnati and Washington, D.C. was being planned at the end of World War II. Coal was the big money maker, however, and comprised 77 percent of the freight tonnage carried in 1945; merchandise freight contributed another 37 percent. The line hauled a little over 12 percent of all the bituminous coal in the United States in 1945 (Wallace 1947: 108).

Another market for C&O-carried West Virginia coal developed in New York, where steamships, the elevated subway, and even the New York and New Hampshire Railroad became major consumers--on the order of 2,000,000 tons of New River coal annually--in the late nineteenth century. Subsequently, however, the New York market was closed-off to West Virginia coal by competition from the Pennsylvania Railroad, which cut its coal freight costs to the New York market dramatically. For good measure, the Pennsylvania Railroad's A. J. Cassatt and the New York Central Railroad, also purchased some 40 percent of the stock of the C&O in late 1899 for $9.5 million (Martin 1992: 153-154) and raised the freight rate on West Virginia coal that the C&O carried to its deep water terminal at Newport News from $1.00 to $1.40 per ton (Wallace

1947: 92). These two steps effectively blocked West Virginia coal from entering the New York market.

Before the Interstate Commerce Commission stepped in and forced a widespread divestiture of railroad stock by 1906, the Pennsylvania Railroad had extended its substantial influence over the nation's railroad business at the beginning of the twentieth century by purchasing a 40 percent interest in the Baltimore & Ohio Railroad for $65 million and a 39 percent interest in the Norfolk & Western Railroad for $17.9 million (Martin 1992: 154). With four other railroads, the C&O in 1904 also operated rail lines between Columbus and Toledo, Ohio, and in 1910 the C&O had a one-half interest in the Kanawha and Michigan Railroad (Wallace 1947: 92, 96). Chicago was added later to the list of cities the C&O served as the Great Lakes region and the city of Chicago evolved into economic powerhouses in the late nineteenth and twentieth centuries. Thus, like other major railroads, its influence spread out widely, and its lines wove together the economies of many cities in a national transportation web.

The direction of coal shipping changed radically with population growth, competition from other rail lines, and increased industrialization in the West and Midwest in the twentieth century. By the 1940s, the coal shipments from Huntington moving west exceeded those moving east by three to one (Wallace 1947: 92).

Huntington also became the site of major train workshops, including an early engine house that could hold 42 locomotives, a smith shop, foundry, machine and car shops, a brick passenger station, and 14 homes for the shop employees. A branch of the C&O Hospital Association was set up at Huntington in 1900 an provided that town with an important medical service.

Thus, Huntington was first a railroad town, but one that also had excellent water transportation possibilities. It therefore became a product redistribution center. Since cheap supplies of coal and gas also were available nearby, manufacturing became a major economic focus as the town matured in the nation's industrial era. Beginning in 1888, electric inter-urban car lines were constructed to serve the growing town population. These were consolidated in 1899, the same year that natural gas began to be piped from Warfield, Kentucky, to Huntington for both heating and light. Six years before, the Huntington and Kenova Land Company had begun development of a neighboring town called Central City, where a broom factory and a brick kiln had operated. The company attracted three glass factories to their development that operated for a number of years (Wallace 1947: 8-18).

After 1903, Huntington experienced a considerable growth spurt when the Huntington Land Company was formed. A federal post office was built in the town in 1908. Early twentieth century industries in Huntington included brick making, ice making and brewing, packing houses (Armour & Company), lumber and box-making businesses, and a veneer-making plant. A major industrial presence headquartered in Huntington but with much wider importance was the Island Creek Coal Company (Wallace 1947: 255-281).

The importance of the railroad to early Huntington's economy was underscored by the presence of the American Car and Foundry Company, dating to 1871, which produced railroad freight cars, wheels, mine cars, forgings and pressings that were used in many countries. The Duncan Box and Lumber Company began operations in Huntington in 1895 and produced all manner of wooden shipping crates. The West Virginia Steel and Manufacturing Company occupied some 23 acres along the Ohio River frontage at Huntington after its organization in 1907. Huntington also continued its tradition in glass making. A glass plant was operated there by Charles Boldt beginning in 1913. Michael J. Owens, who learned the glass-making business in Wheeling, took

over the Boldt plant in 1918. Owens later became an internationally recognized inventor of glass making machinery that automated the glass bottle manufacturing process in the early twentieth century. In 1929, the firm merged with the Illinois Glass Company to form the Owens-Illinois Glass Company. In addition to the Huntington plant, the company also operated plants in Charleston and Fairmont, West Virginia, and in many other cities across the country. Owens-Illinois provided jobs to 1,133 people in Huntington in 1947 (Wallace 1947: 143-157). Other important industries that developed in Huntington included the Standard Ultramarine Company (a dye manufacturer), the International Nickel Company (began operations in 1922), the Armstrong Products Corporation (a maker of gas stoves, lawn sprinklers, electric heaters and ironers, etc.), a specialty metals manufacturer, and a branch operation of the Pittsburgh-based Westinghouse Electric Corporation, among others (Wallace 1947: 153-165).

Cincinnati

The earliest eighteenth-century explorations near the present site of Cincinnati date to 1754 and again in 1767, but the dangers of the region prevented any attempts at permanent settlement. Upon their return from attacks on the Indian towns at Piqua and Chillicothe in 1779, the troops of George Rogers Clark constructed a blockhouse at the intersection of what is now Front and Main Streets in Cincinnati. The purpose of the blockhouse was to protect the Licking River settlements on the Kentucky side of the Ohio from attacks originating in northwest Ohio. Thus, the first evidence of any substantial building on the subsequent site of Cincinnati was rooted in the military necessities of the time.

After the Revolution, Benjamin Stites of New Jersey visited the Cincinnati area while on a trip to Limestone, Kentucky (current Maysville), one of the few early settlements to take root on the Kentucky south side of the Ohio River. Stites was impressed with the possibilities of the region and encouraged other settlers from New York and New Jersey to emigrate. Stites' enthusiasm also attracted the attention of New Jersey politician John Cleves Symmes, who eventually bought the whole tract. From this purchase, Symmes reserved for himself one township at the mouth of the Big Miami River and its confluence with the Ohio. Recognizing the potential advantages of the location, Symmes planned to build a town to be called North Bend.

In 1788, Mathias Denman, another New Jersey resident, bought a plot of ground within Cincinnati's current boundaries. Denman divided his land into thirds, kept one-third for himself and sold the other lots to Robert Patterson and to Kentucky schoolteacher John Filson. Filson's name already was well known on the frontier through his 1784 publication, Discovery, Settlement and Present State of Kentucky. The book also had been translated into French in 1785. It was reprinted in English versions in 1792 and 1793. Filson's boosterism and that of other writers advertised the conditions and opportunities of the American West to a wide national and international audience and helped attract many new settlers to the Cincinnati area.

Like Symmes, Denman, Patterson, and Filson also planned to lay out a new town on the north side of the Ohio. They proposed to construct their town opposite the Licking River and to establish a ferry across the Ohio connecting their settlement by road with the rapidly developing town of Lexington. Both Stites and Symmes also went forward with their competing town-making schemes. Symmes enticed prospective buyers by offering land at cheaper prices to those who bought first. Each purchaser was bound by the terms of the deal to begin improvements within two years, and was offered certain inducements for staying on the land for three successive years. In this way, Symmes hoped to stem one of the major problems for most new towns in the Ohio Valley—keeping the people they initially attracted. The seemingly pervasive restlessness of western settlers and their haste to move on into ever newer western lands produced large

turnovers in Ohio River town populations. The rapid population turnover , in turn, contributed to the fast-paced, rootless, free-wheeling, highly individualistic, impermanent, and often lawless quality those early settlements took on, and threatened their economic and social prospects.

In mid-November 1788, 26 persons from Stites' group came by boat from Limestone, Kentucky, to the junction of the Little Miami and Ohio rivers, where they constructed a stockaded blockhouse. This was the beginning of a settlement that Stites called Columbia. On Christmas Eve the same year, the small community of Losantiville, which grew into Cincinnati, was started five miles down the Ohio from Columbia near General Clark's old blockhouse of 1779 (Chambrun 1939: 50-56).

In 1789, Mother Nature and the Ohio River chose among the three competing town sites of North Bend, Columbia, and Losantiville. The floods that spring left no doubt that the sites chosen for North Bend and Columbia were less than ideal. Only Losantiville was elevated far enough above the river to emerged unscathed. As a result, General Josiah Harmar selected the area east of Losantiville for the erection of Fort Washington. This was a substantial military structure, 200 feet square, and one of the fortifications the Americans were building in the Ohio River Valley to protect new settlements and as bases for military operations against the Indians in northwest Ohio. The presence of the fort offered protection for the little settlement at Losantiville but also contributed residents. The garrison numbered 140 men in 1789, and 350 additional troops came with Harmar in January 1790. General Arthur St. Clair soon came to the new fort from Marietta, established Hamilton County (not coincidentally named after Alexander Hamilton), and changed the name of Losantiville to Cincinnati to honor the Society of the Cincinnati (Chambrun 1939: 57-58). The choice of name seemed appropriate not only to honor the Revolutionary War officers' society but to embrace the symbolism of the old Roman ideal of the farmer implored to take up arms but who later returned to the land, the citizen soldier who would rather be at his plow. Thus, in a very brief time Cincinnati had built on its initial advantage of location on the Ohio River. It was relatively safe from floods, was the site of a major new fortification, and had attracted a sizable contingent of troops, "camp followers", and civilians—all of whom had to be housed, fed, and supplied. The fledgling community was, in turn, afforded a measure of military protection that harbored its early growth and had achieved recognition and local prominence as the focal point of a newly established county.

The new settlement of Cincinnati was soon tested by the stinging military defeats of both Generals Harmer and St. Clair. It persevered through the troubled years between 1790 and 1794, but only Anthony Waynes's victory at Fallen Timbers in the latter year and the resulting Treaty of Greene Ville in 1795 conveyed a peace in which growth could resume.

Other towns soon blossomed in the Northwest Territory as well. Dayton was established by promoters who originated in Cincinnati. Chillicothe, the ancient site of Indian settlement, was set up out of Massieville on the Ohio River at the confluence with the Scioto River, a town that later became Portsmouth. Zanesville and New Lancaster also were founded.

Despite the appearance of these new and competing urban centers, however, the population of Hamilton County and Cincinnati in 1798 already had outstripped other areas of Ohio. It stood at something on the order of 4,000 white male inhabitants at the time (Chambrun 1939: 76). The meteoric population growth attracted new political attention as well. As Ohio prepared to enter the union in 1803, the capital was moved down the river from Marietta to Cincinnati, but protests from rival towns got it moved to Chillicothe, though it returned to Cincinnati again before moving permanently to Columbus. In 1803, Cincinnati had a population of perhaps 1,000. Most of the early log cabins had given way to frame houses of which there were now about 110.

The streets connecting the town to the Ohio River had been graded, and trees on the first terrace below the town had been cleared away giving unimpeded access to the all-important river. The wharf area was the center of trade and commerce. Not only had the town's population grown, it had diversified as well. There were some 24 merchants in the town plus numerous artisans and professional men, primarily lawyers. Lawyers often were the most formally educated of the town's population, and their presence added to Cincinnati's youthful but evolving cultural, artistic, and literary life. Over the next 30-40 years, a socially elite nucleus of professionals, established businessmen, manufacturers, and merchants would emerge and lend Cincinnati the high degree of social coherence, business acumen, and community leadership needed to govern and guide a town whose population was doubling in every decade of the first half of the nineteenth century (Glaser 1999: 8, 14).

Important technological changes were soon to make their presence known as well. In October 1811, Cincinnati received the New Orleans, a Pittsburgh-built steamboat and the first of its kind to descend the Ohio River. Low water prevented the boat from continuing down the Mississippi until December, so in the meantime it traversed the Ohio back and forth between Cincinnati and the Falls of the Ohio at Louisville. This inaugurated the steamboat era on the Ohio and Mississippi River system.

The materiel needed to fight the War of 1812 was good for the early industrial and commercial economies of Ohio River towns, but the economic ebullience fell hard in the post-war downturn. Much like Filson's writings a generation before, publication of Daniel Drake's Picture of Cincinnati in 1815 renewed public curiosity and interests in the city and did much to encourage the arrival of new residents.

By 1819, 70 steamboats plied the river trade from Pittsburgh to New Orleans and back (Chambrun 1939: 118). Cincinnati soon became one of a number of urban centers of steamboat construction along the Ohio. The steamboats also increased the scope and diversity of the river trade to and from towns. Raw materials, agricultural produce, and livestock rolled into the town's workshops, markets, and slaughterhouses. These were transformed or processed into tools, furniture, clocks, paper, hats, books, flour, whiskey, beer, porter, linseed oil, lard, bacon, and pork. Cincinnati became so famous for its pork and pork products that the boosters of competing cities dubbed it "Porkopolis" (Chambrun 1939: 125).

A census of the town in 1818, the year it was incorporated, showed that just 30 years after its first tenuous beginnings, Cincinnati's population stood at some 8,000 whites and 367 African Americans. There were then 1,000 houses; 95 stores; 100 groceries; 11 drug stores; 5 print shops; 214 factories, mills, and mechanics shops; 17 taverns, 400 warehouses, a sugar refinery; a glass factory, churches, etc., all-in-all, some 1,900 buildings of which 200 were constructed of brick or stone (Chambrun 1939: 131). A large percentage of the city's business was oriented to river commerce, but by the 1830s and 1840s manufacturing was on the increase as well (Glaser 1999: 8). By 1828, the monetary value of the town's exports already exceeded $2,500,000 (Chambrun 1939: 125) and amounted to $6,000,000 in 1835 (Roseboom and Weisenburger 1986: 122). Population growth increased Cincinnati's numbers to 30,000 by 1830 (Chambrun 1939: 188). Ten years later, almost half of all the money invested in Ohio manufacturing had been plowed into Cincinnati firms (Roseboom and Weisenburger 1986: 123).

As in many other towns at the time, disease and medical ignorance of its causes detracted from the generally positive run of social, business, and institutional growth that Cincinnati enjoyed in the ante-bellum period. Cholera outbreaks occurred in 1832, 1834, and again in 1849. A flood in 1847 also took a toll on the town.

The comparatively high costs of transporting iron products to the West from the iron production and working center at and near Pittsburgh soon led to the establishment of iron furnaces and foundries in Ohio. Muskingum County was the site of early cast iron production of stoves and other useful products from bog ores. The opening of the Erie Canal offered this early industrial center an important new outlet for its products. In the ante-bellum period, a large charcoal iron industry also developed on both sides of the Ohio River in the so-called Hanging Rock District. In 1849, 17 hot-blast and five cold-blast iron furnaces were operating here (Roseboom and Weisenburger 1986: 122). Much like the earlier relationship that Pittsburgh had enjoyed with iron furnaces in central Pennsylvania, and in the Allegheny and Monongahela River Valleys, the Ohio furnaces supplied pig iron that was worked into finished products in Cincinnati's foundries.

By 1850, the 30,000 inhabitants of the town 20 years before had grown to 115,000. Cincinnati then stood as the fifth largest city in the country and its second largest manufacturing center (Glaser 1999: 7). It had long before become the major metropolis of the Middle Ohio River Valley. Railroad growth in Ohio between 1850 and 1855, however, favored connections to other cities such as St. Louis and Chicago. The older towns along the Ohio River were to some extent, passed by. Cincinnati fared well during the Civil War but its economy, particularly its down-river trade with the South was hurt by the disappearance of southern markets after the war.

The January 1884 a flood decimated the city's gasworks, wiped out 1,500 businesses, and made about 2,000 people homeless. Covington, Kentucky, on the opposite side of the Ohio, also was hard hit. Weakened homes collapsed, and schools closed or were washed away. A large lake was created up the Miami River by impounded waters in the Ohio that reached a flood crest of 71 feet and one inch (Chambrun 1939: 265-266).

Despite such losses, the growth of the city was spurred on by the arrival of new rail lines, eventually numbering seven trunk lines in all, and by the erection of the magnificent Union Station during the Depression years of 1929-1933. The new station consolidated the freight and passenger rail operations in the city. The seven lines that served Cincinnati in the 1930s drew on a network that amounted to 20 percent of all the rail lines functioning in the United States(Chambrun 1939: 301-302).

About this same time, the Mississippi Valley Barge Line built a freight river terminal, crane, and a freight depot that allowed the rapid transfer of freight between river barge and truck and river barge and railroad. This made good use of the greater Cincinnati area's 23 miles of river frontage. A broad road was built to give trucks access to the river terminal. The barge line also operated four large twin-screw propeller tows and 50 steel barges as part of Cincinnati's new freight-handling complex. These new constructions took advantage of the Corps of Engineers' completion of the Ohio River Navigation System in 1929 for the cost-effective river transport of freight. As a result of the synergy derived from the implementation of river navigation improvements and the construction of urban terminals, river-borne freight at Cincinnati increased from less than 2,000,000 tons annually in the 1920s to nearly 3,500,000 tons by 1935 (Chambrun 1939: 304-305, 309).

In the 1930s, industrial Cincinnati included some 1,400 manufacturers employing 40,000 workers. The effective area of industrialization extended outward from the city itself to included four counties in Ohio and across the river in Kentucky. Leading businesses and industries in the 1930s included meat packing (and the allied dairy, leather, soap and candle industries), malt liquors, bakery products, and furniture making as well as steel, iron, machine tools, petroleum products, and electrical appliances. Cincinnati was second only to Chicago in the meat packing

industry at the time. Eighty-eight manufacturers in Cincinnati specialized in the production of men's and boy's clothing, while 160 others were involved in publication of newspapers and journals. The list of early Cincinnati businesses and the trade names coined in the "Queen City" still have meaning in contemporary American commerce—Proctor & Gamble, Jergens, Kroger, Fleischmann, and Baldwin to name a few (Chambrun 1939: 309-317).

ECONOMIC BENEFITS OF THE OHIO RIVER NAVIGATION SYSTEM

From the information presented above, it is clear that urban life has been an important part of the Ohio River Valley's history from the arrival of the first Euro-Americans settlers in the late eighteenth century. For many of these newcomers, town life was an already familiar experience. Before they moved to the Ohio country, a significant number of them had lived in eastern towns, had participated in, or had benefited from the economic, social, legal, educational, and other functions that urban institutions provided. Town-building, therefore, went hand in hand with the settlement process.

In a day when rivers represented the only real highways of travel, communication, and commerce, most early towns in the Ohio River Valley were founded on the Ohio River itself, often at its confluence with tributary streams or rivers. A water-side location was a significant factor in their economic prospects. It is therefore unsurprising that many towns and cities in the Middle and Upper Ohio River Valley, including both of that region's entrepots, Pittsburgh and Cincinnati, were settled at an early date. These first towns developed when and where they did largely due to the fact that the Ohio River conveyed an "initial advantage" in trade, travel, and transportation over other locations. The relative economic standing of the valley's major urban centers has experienced comparatively little change over the last two centuries. Pittsburgh and Cincinnati were as important to the economic vitality of the Ohio River Valley at the beginning at the nineteenth century as they are at the start of the twenty-first. It is true that Huntington, West Virginia, has developed into a major river port city largely due to its oil, gas, coal, and chemical industries and to its excellent rail connections, but this more recent economic growth has not diminished the larger cultural significance of either Cincinnati or Pittsburgh.

Given the importance of urban life to the history of the Ohio River Valley, it is ironic that there have been so few formal studies of the river's contribution to the culture, economy, and population of its towns. Rarer still are studies of the impacts of the Ohio River navigation system on urban life and economy.

In general, historical geographers and historians have paid insufficient attention to the importance of the Ohio River and its navigation system on the development and growth of river cities and towns in the Middle and Upper Ohio River Valley. The rarity of comparative studies of the river's impact on urban economies poses considerable challenges to understanding the more specific effect of the Ohio River navigation system on river-side towns. Although historians of the nineteenth and the first half of the twentieth centuries acknowledged the river's significance for town life, their work focused largely on the creation of historical narratives, chronicles, and descriptive histories. This earlier generation of historians chronicled, preserved, and presented much interesting and colorful information about pioneer life on the river and in early river towns, and they painted often vivid verbal portraits of the Ohio River Valley as part of the nation's great westward migration, but little attempt was made to quantify the contribution of the river to the urbanization process.

The relatively late construction of the Ohio River Navigation System, extending from the late nineteenth century into the early decades of the twentieth century, also has acted to limit the historian's evaluation of the system's consequences for urban life. Since the completion of the first great era of railroad building between 1850 and 1860 the economic success of Upper and Middle Ohio River Valley towns has not been directly tied, as it was for all practical purposes before that time, to the river. The river navigation system, moreover, was completed at a time when commercial river traffic in general was falling off due to the combined impact of the

railroads and the subsequent emergence of the nation's highway system. The appearance and growth of these forms of transportation—both of which have had major effects on urban life in the river valley—also have acted to blur recognition of the continuing but "lower amplitude" contribution of river commerce to contemporary urban life, especially in the cost-effective transport of bulk commodities such as coal and steel products, petroleum, and chemicals. The contribution of the river and its navigation system, thus have been largely overlooked.

One of the few specific studies of the economic benefits of the Ohio River Navigation System was conducted by Joseph R. Hartley (Hartley 1959), at the time an assistant professor in the Indiana University School of Business. Noting the difficulty of undertaking the study due to the lack of basic economic research, Hartley set out to examine "...the economic characteristics of the river navigation industry" (Hartley 1959: Introduction). He also tested an earlier conclusion of the Hoover Commission that, in Hartley's words, "...decided in it's (*sic*) studies that benefits from river transportation were generally local and that only a few, large industrial companies used the rivers" (Hartley 1959: Introduction). He also evaluated another Hoover Commission conclusion that the lower transportation costs enjoyed by these companies probably did not result in lower consumer prices except indirectly.

In contrast to the conclusions of the Hoover Commission, Hartley's economic analysis of the status of commerce on the Ohio River and of improvements to its transportation system in the mid-1950s concluded that the country as a whole had benefited greatly from improvements to this waterway. Unfortunately, Hartley's study did not specifically address the navigation system's economic benefits to Ohio River Valley towns and cities; thus, one must extrapolate from his conclusions for the Ohio Valley as a whole.

Hartley found that river shipping had experienced a dramatic decline in the late nineteenth and early twentieth centuries due to the national growth of railroads and, beginning in the 1920s and 1930s, to the development of long-haul trucking. However, inland river shipping had made a significant comeback, growing from 20 billion ton-miles in 1939 to 120 billion ton-miles in 1957. Barge tonnage carried on the Ohio River in 1957 actually was larger than that on the Mississippi River if coastal traffic on the Lower Mississippi River was excluded (81.6 million tons vs. 74.6 million tons on the Mississippi). Hartley also was encouraged by the 9.5 percent annual growth rate in the number of ton-miles carried on the Ohio and its tributaries, rising from 1.5 billion ton-miles in 1929 to 17.2 billion ton-miles in 1957. Most of this consisted of coal and coke (32.9 percent of ton-miles and 54.7 percent of tonnage in 1957) followed by petroleum (34 percent), iron and steel (19.9 percent), chemicals (7.6 percent), and other commodities (5.6 percent). Actual tonnage had increased from just 22 million tons to 81.6 million tons over the same period.

The reasons for this dramatic economic improvement on the Ohio River system included technological developments in barge design, construction and method of towing. Steel barges had supplanted the old wooden ones, and integrated tows now permitted up to 30 barges (the equivalent of 4-5 trainloads) to be joined together in a single tow. Other technological changes included the installation of radar and the adoption of diesel engines. The result was the capacity to haul a larger number of barges at lower cost, and with fewer accidents.

Another major factor that Hartley singled out as contributing to the rebirth of Ohio River freight transportation by the mid-1950s was the improvement of the river itself. Hartley attributed much of the economic benefit resulting from improved water transportation to the removal of snags and sandbars and the construction of the system of locks and dams on the river by the U.S. Army Corps of Engineers that was transforming the river into a "superwaterway" (Hartley 1959: II).

Water transportation rates also compared favorably to railroad rates in Hartley's results. In 1957, water-borne commerce averaged about 0.4 cents per ton-mile, whereas rail rates then ranged about 1.4 cents per ton-mile. Furthermore, the gap between these rates had widened since World War II. Barge rates had increased more slowly than railroad rates, due in part to the federally supported costs of waterway maintenance and to the increased productivity that had resulted from technological changes in tows, barges, and locks. Although barge rates for coal had increased "a small amount" since the end of the war, the rates for carrying petroleum had declined about 50 percent their war-years high (Hartley 1959: II).

In contrast to the Hoover Commission's contention that cost savings of water-borne transportation were, at best, only passed on to consumers indirectly, Hartley's study found that the economic competition among the 935 individual barge lines then in operation on the Ohio-Mississippi system as well as competition from the railroads helped to keep freight rates low. Furthermore, the competitive atmosphere assured that this savings was passed on to shippers and consumers.

As of 1957, Hartley found, the states bordering the Ohio River were responsible for producing 84.8 percent of the nation's supply of bituminous coal, and the proportion of coal carried by river barge had steadily increased from 1929 onward. Hartley found that those coal mines in southern Indiana without access to Ohio River tributaries had lost market share to other areas.

Hartley also concluded that transporting coal on the Ohio River to industrial consumers, many of them electrical generating plants built on the river flood plain, had kept the cost of both coal and electrical power down for millions of ultimate consumers. Ohio River electrical plants, Hartley discovered, were producing about 12 percent of the nation's electrical supply in 1957, up from 6 percent in 1939. River transportation of coal to these plants allowed them to save nearly one-third the cost of production when compared with the national average. Since these electrical generating plants also were developing transmission lines to towns and cities within 100-150 miles of the river, the benefits of cheaper electricity was being shared with urban centers far removed from the Ohio River itself (Hartley 1959: III).

Construction of the Ohio River Navigation System also had eliminated the large seasonal variations in pool depth. This year-round availability of water directly benefited the production of electric power and the output of industrial (especially steel) plants in the Ohio River Valley. The Ohio River Valley steel industry near Pittsburgh had long used the river to ship coal from mines up the Monongahela River Valley and had begun to ship finished steel products by river in the 1920s (see Carlisle 2000b). During the industrial boom period of the mid-1950s, Hartley (1959: IV) found that a "large volume" of steel was being shipped by river as far south as Texas and that its availability at river-side towns was attracting other steel-using industries. Hartley's study found that $13 billion dollars had been spent on the construction of industrial facilities in counties bordering the Ohio River and its tributaries since 1950 (Hartley 1959: IV).

Development of the Ohio River Valley's aluminum industry also was directly related to that industry's need for large amounts of electrical energy used in smelting. Aluminum smelters were established in the Ohio River Valley for the first time during the 1950s to take advantage of lower cost electricity and to capitalize on river shipments of raw materials, especially alumina, and finished aluminum products (Hartley 1959: III).

Hartley's study also found that cheap river transportation had influenced the post-war development of the petroleum and chemical industries in the Ohio River Valley. By the mid-1950s, construction of oil pipelines had taken away a good deal of the river trade in crude

petroleum, but river barges transported higher-value petroleum products such as gasoline, diesel fuel, and refined oils to distribution points, including the towns and cities on the river. The costs of these products at the point of distribution were lowered by using cheaper river transportation rather than the railroad.

Barge transport of chemicals had grown in the post-war years, Hartley discovered, due in large part to the development of containerized shipping technology, to low transportation costs, to increasing demand, and to the chemical industry's need for large volumes of water used in chemical processing. As a result, the chemical industry on the Kanawha River, a tributary of the Ohio River in West Virginia, had grown into the one of the nation's largest (Hartley 1959: IV).

Although he did not investigate the economic specifics, Hartley (1959: IV) also proposed that construction and maintenance of the Ohio River Navigation System also may have played an important role in the continued evolution of other forms of transportation in the river valley, including the rival railroads, an idea that he felt merited additional research.

In sum, by the mid-1950s, the development of the Ohio River Navigation System had helped to sustain lower costs for delivered coal, had provided cheap but reliable water supplies, and had lower prices for steel and other industrial transportation. These economies, in turn had helped to keep down energy prices and the cost of steel-using durable goods (such as automobiles, stoves, and refrigerators) for individual consumers. River transportation also had boosted the prospects of the aluminum smelting industry and the chemical industries in the river valley. Prices for refined oil and petroleum products used in the rapidly growing number of automobiles now being driven on the nation's expanding interstate highway system were held down by lower cost barge transportation.

All of these matters were important considerations in the post-war America of the 1950s where the "baby boom" and the rapid development of suburban family housing had increased the demand for affordable energy and an ever-increasing number and variety of consumer products. Although the cost benefits of river transportation radiated outward to the nation as a whole, Hartley found that the Ohio River Valley had benefited directly from increased industrial investment, job growth, greater per capita income, higher retail sales, and urban growth. The last three categories were higher in the Ohio River Valley than for the nation as a whole even though, Hartley concluded, the overall prosperity of the Ohio River Valley still lagged the rest of the country. In general, Hartley (1959: IV) concluded, "Improvement of the River has helped provide an economic base for healthy, sustained, and rational economic growth."

COMMUNITY GROWTH AND RIVER NAVIGATION IMPROVEMENT IN THE LOWER OHIO RIVER VALLEY

Long before the first Europeans reached the Ohio River valley, Native Americans had settled along its banks and used the river to travel and trade among numerous settlements. These trade networks were quite extensive, especially during the long period of mound-building cultures, beginning with the Adena culture shortly before 900 C. E. and continuing through the Hopewell and Mississippian periods. While these cultures were extinct by the time of the arrival of the French in the Ohio Valley in the middle of the seventeenth century they point to the central role of the river, as a transportation artery, in sustaining permanent settlements of significant size.

Various Indian cultures were in the region before European contact, known sequentially as the Archaic, Woodland, and finally the Mississippian. They represent the earliest human occupation of the area. The Archaic and Woodland cultures have left little evidence with which to reconstruct their way of life. There is a great deal more evidence from the Mississippian culture which flourished in the central Mississippi and Ohio valleys before white contact, between 1200 and 1500 A. D. Distinctive earthen mounds, generally built on highlands near a river are characteristic of this culture. The mounds were part of settled villages, which were occupied for long periods by farmers whose cultivated fields were in the rich river bottomlands.

A review of the archeological literature suggests that after the decline of the Mississippian civilization around 1500 A. D. the Lower Ohio River Valley was sparsely settled. There is little evidence of settlements of any size or duration of occupation during the period following initial contact with white settlers and explorers. A number of tribes used the area as a hunting and fishing ground, using the rivers and their tributaries as well as the Buffalo traces that crossed the region. These tribes include the Creeks, Chickasaw, Choctaw, Shawnee, Yuchi, and Cherokee. All of these tribes suffered from disease during the eighteenth century that led to severe population decline. These diseases were the result of the initial exposure of Indians to European diseases from which they had been isolated for many generations. The sudden loss of population disrupted their traditional way of life and reduced their ability to resist incursions by European settlers. Klotter and Harrison in the *New History of Kentucky* estimate that by 1750 there were no more than three to four thousand Shawnee in all of Kentucky. (Klotter and Harrison,1997: 8)

The French were the first Europeans to enter the Ohio Valley and settle it. France had extended its North American possessions toward the Great Lakes very rapidly after establishing Montreal and Quebec early in the seventeenth century. They then moved down the Mississippi and along its many tributary streams, including the Ohio. Missionaries and fur traders spread across the lakes as well as the rivers and stream of the lakes region rapidly and frequently encountered Native Americans who described a great river flowing west and then south.

Whether Rene Robert Cavelier, Sieur de La Salle was the first to see the river or it was Louis Joliet and Pere Jacques Marquette, by 1674 the lower parts of the river were on French maps of America. The upper river remained unknown to the French for some years more. French interests were focused on the fur trade and looked to the Ohio and its tributaries as a transportation system to move furs to Montreal and Quebec, via the Great Lakes. The settlements established by the French were entirely concerned with protecting this trade route and operating it. The river as transportation artery was central to French settlement of the region and their economic development of it. "Early descriptions of the Ohio River emphasized its navigability, often stating that no serious problems were met in traveling except at the Falls." (Johnson 1974: 21) Of course,

the early explorers had relatively small, shallow- draft vessels for which the natural channels were adequate and the shifting bars, rocks, and snags easily avoided. As Johnson goes on to say, "As the Ohio Valley was settled and extensive use of the rivers for marketing agricultural produce and manufactured goods developed, obstructions to navigation, because of the resultant delays and losses of boats and their cargoes, became more objectionable." (Johnson 1974: 21)

The first whites to enter the area appear to have been French fur traders following the Mississippi and Ohio river systems to the Tennessee. The French had long been active in the Mississippi Valley and had several settlements in the Illinois Country, as part of their extensive fur trade network. A 1701 French map depicts the Tennessee River accurately, indicating familiarity with the region. The French hunter and trader Timothy De Monbruen was active in the area between the rivers as early as 1769 before settling permanently at Nashville, Tennessee. He is one of the few French who were active in the area who can be identified by name.

British and American hunters, trappers, and land speculators were also active in the area, especially after the Treaty of Paris of 1763, at the conclusion of the French and Indian War, gave control of all the territory east of the Mississippi River to Great Britain. The work of Col. Richard Henderson of the Transylvania Land Company has already been mentioned. Col. John Donelson, another early settler of Nashville, was in the area from 1779-80 on a hunting expedition. Donelson met Henderson in the area between the Tennessee and Cumberland rivers in 1780 while Henderson was surveying the boundary line between North Carolina and Virginia, both of which had claims to the area. Henderson was working for North Carolina, while Dr. Thomas Walker and Daniel Smith conducted a similar survey for Virginia. The importance of the west to those in the east can be seen in the failure of the Revolutionary War to deter or delay these efforts to explore the west. The two colonies/states were unable to resolve their different interpretations of their boundary and the issue remained unresolved until 1860. By then the dispute was between the states of Kentucky and Tennessee, which had been formed from the western parts of the two coastal states.

The boundary surveyors were followed by other surveyors by 1783 when North Carolina began issuing land warrants for military serviced during the revolution. Land warrants were an established way to encourage and reward military service by cash short governments and service reward. The warrants were the vehicle for the early settlement of lower Ohio Valley. Many, if not most, of the early settlers came from North Carolina in the years after the American Revolution to take up land with warrants from their service in the Revolution. The earliest settlers built log cabins and established farms in the river bottomlands and along the creeks where the land was more fertile, there was a sure source of water, and the river provided transportation for surplus crops, once they were being produced.

The influx of settlers in far western Kentucky lead to some increase in conflict with the Indians. The United States interpreted the Treaty of Paris of 1783 that had transferred all of the land east of the Mississippi to the new government as extinguishing Indian claims and opening the land to settlement. The lack of Indian settlements in the area south of the Ohio made it easier for settlement to move forward, but conflict with the Indians continued and there was considerable interest in an agreement with the Chickasaw, the main Indian group with a claim to the area for a settlement that would make settlement safer. The Hopewell Treaty tried to do this, drawing a line at the Tennessee River, but as settlers moved into the area, they were drawn to the area west of the Tennessee as well.

Col. Richard Henderson of the Transylvania Land Company boundary agreed to the Treaty of Sycamore Shoals with the Cherokee in 1775. Henderson purchased recognition by the Cherokees

of the Transylvania Company's claim to all the land east of the watershed of the Cumberland River, opening it, he hoped, for unmolested settlement. The treaty created a line between Indian territory and lands open for settlement that followed the divide between the watersheds of the Tennessee and Cumberland rivers in the land between the rivers. In the Treaty of Stanwix in 1768 the Indians had ceded the territory between the Ohio and Tennessee Rivers. The Treaty of Sycamore Shoals was an attempt to avoid the conflict between Indians and settlers that had already become a regular aspect of life on the frontier, especially in Kentucky and Tennessee. The danger of Indian attack inhibited settlement and restricted the ability of the Transylvania Company to settle its land grants.

The Treaty of Sycamore Shoals did not accomplish what Henderson had sought. The Cherokees were not the only Indian tribe with claims to the territory and the other tribes did not feel bound by a treaty to which they had not agreed. The treaty did not eliminate Indian resistance to white settlement. In 1780, the Commonwealth of Virginia voided the treaty in the portion of the area involved that was within its boundaries.

The idea behind the treaty line reflects an important concern during early efforts to settle the region – security from Indian attack. Despite Henderson's attempt, deadly conflict between pioneer settlers and Indians was common.

The Hopewell Treaty of 1786 reserved all land west of the Tennessee River to the Chickasaw Indians. Although the Chickasaws did not occupy the territory or hunt in it with any frequency or regularity, it was closed to settlement as both the federal government and Virginia, which still claimed all of what would become Kentucky, honored the treaty. As settlement spread down the Cumberland and Tennessee Rivers pressure built to open the unoccupied and unused lands west of the Tennessee River for settlement. In 1818 Andrew Jackson of Tennessee and Isaac Shelby of Kentucky negotiated the transfer of this tract. The Chickasaw Purchase Treaty was signed in October, 1818 and ratified by the Senate in January, 1819. The treaty was known popularly as the Jackson Purchase and that name has remained attached to the westernmost sections of both Tennessee and Kentucky ever since.

While there were some settlers, primarily French and Metis and a few Americans, in the region at the time of the American Revolution, extensive settlement did not begin until approximately 1790 and the Ohio, and its tributaries, especially the Tennessee and Cumberland, were the major "highways" for settlers. The Ohio River Valley quickly passed through the pioneer, subsistence farming phase, and transportation became a critical concern for the future development of the region. Water transportation, the river, was the only practical way to ship the region's agricultural products to market or to bring in manufactured goods and other things that could not be produced locally. When local manufacturing began the river was important for bringing in raw materials and the distributing the manufactured products. The Ohio River, as the main transportation artery, played a central role in the economic development of the region from the very beginning of settlement and has played a significant role in the establishment and development of industry and communities ever since. While there were numerous settlements along the many tributary streams that flow into the river, the Ohio was the principal transportation link with the larger world and the focal point for trade and industrial development.

Such an important role for transportation and a transportation artery is not surprising. Central Place Theory, as initially presented by Walter Christaller in the 1930s, and developed by several generation of economic geographers since, considers transportation as one of the three principle factors in determining settlement location and development. Communities should appear at the interval of a day's journey, and at the mouth of tributaries, and at major obstacles to free

movement along rivers. Their development should be proportional to the productivity and size of their hinterlands. To a considerable degree the actual pattern in the lower Ohio River Valley, the focus of this essay, conforms to theoretical expectations. Pittsburgh is located where the Allegheny and Monongahela come to form the Ohio River. Louisville, the largest and most important place in the lower Ohio Valley, is located at the Falls of the Ohio, the most significant break in navigation on the river. Other lower Ohio Valley communities such as Evansville, Paducah, Smithland, Owensboro, and Henderson, among others are located at the confluence of significant tributaries. Their growth and relative size has been strongly influenced by the size and economic prosperity of their hinterlands. However, central place is not a perfect predictor. Cairo, Illinois, for example, has never reached the size and economic influence in the region that its location at the confluence of the Ohio and Mississippi Rivers would seem to predict.

There are several factors that explains this, some of them cultural. However, if we consider the concept of "points of attachment" set forth by Vance (1970), the case of Cairo and the overall urban hierarchy of the Ohio Valley becomes clearer. In a closed economic system, where most economic exchanges are internal, central place is a good predictor of location and hierarchy. In open systems, however, in which a significant portion of economic exchanges are external - with other economies - places appear that are much larger than central place would indicate. The classic example of this model is the development of colonial seaport towns in the United States, (and their non-development in the Tidewater of Virginia) whose size was related much more to their role in the a larger international maritime commercial economy, specifically as points that connected the nascent colonial economies to that larger economy than to the colonial economies themselves. The relative positions of Boston, Philadelphia, and New York in the national economy over time can best be understood in this way.

When the economy of the Ohio River Valley began to develop the Ohio River was the only effective way to move the agricultural products of the region to market or to bring in manufactured goods from the east and Europe. Because the boats available during this initial stage, flat boat, were limited to movement with the river the region developed a trade pattern that moved with the river. Agricultural products moved down river to New Orleans where they entered the world economy. Manufactured goods from the east and Europe, however, did not come to the Ohio Valley through New Orleans, but from Pittsburgh. Thus the region had two points of attachment to the world economy. New Orleans, of course, is well outside the Ohio Valley. Pittsburgh was established very early as a major city within the region because of its role as a point of connection with the larger national and international economy. When the development first of the keelboat and then, more importantly, the steamboat allowed two-way traffic on the river, Pittsburgh and several other places, principally Cincinnati and Louisville, had already established their positions as key places within the valley economy. With the exception of Lexington, Kentucky, nearly every place in the Ohio River Valley before 1850 with more than 500 people was a river town. Access to water transportation was the key factor in community formation and development. The initial advantage that these three cities gained has been a significant factor in their continuing role as the major economic centers in the region. Their relative position has also been constant.

Vance also helps to understand the growth of communities along the river. The majority of river towns served as points of attachment for their hinterlands with the larger economy. They were the places where goods were shifted from land transportation to water or from smaller vessels for navigating the tributary streams to the larger vessels of trade on the Ohio. The initial development of canals and railroads in the Ohio Valley reinforced these patterns because they were designed to facilitate shipping good to and from the river network. Seeing the communities that developed

along the Ohio River as points of attachment for their hinterlands is a much more useful approach than classical Central Place Theory.

Before turning to a discussion of the relationship between growth and river navigation in the specific communities of the lower Ohio Valley, it is important to understand the overall development of the region's economy and the role navigation of the river has played at different times.

Bigham (1991) outlines five distinct phases for the economic influence of the Ohio River on its region's development. (p. 131) The first phase, from pre-history to the American Revolution is the longest, but also the least importance for our purposes because, while navigation on the Ohio River was important to the region's growth and economic development, there few if any improvements in the natural navigability of the river. The main development of long-term importance was the increasing recognition of the richness of the resources of the Ohio Valley and the value of the river as a transportation artery that would facilitate the development of those resources.

The second of Bigham's phases, from the establishment of the American national government to the 1850s, is a critical period because it saw the establishment of numerous settlements and beginning of a regional economy. The basic patterns, both for settlements and the regional economy, that were established during this period persist to this day. While the size of communities have changed, the basic urban hierarchy of the lower Ohio Valley with Louisville at the top and Evansville as the secondary center have not changed. Similarly, the development of the economies of various communities remains largely linked to access to cheap water transportation. The three phases Bigham sets out following this, from the early 1850s to the early 1880s, the early 1880s to the First World War, and from the first world war to the present, can be seen respectively as the maturation of this river-focused economy, its decline after 1880 because of changes in transportation technology, largely involving the railroad, and finally the river's resurgence as the advantages of cheap water transportation and the region's coal reserves have brought it back to a central role in the economic development of the region.

The rediscovery of the river as central to the culture and economy of the region can be seen in the 1991 initiative of the humanities councils in the states bordering the river, "Always a River: The Ohio River and the American Experience." This initiative has resulted in the publication, to date, of two books (Reid, 1991 and Bigham, 1998) which focus in large part on the central place the river has played in the development of the region's economy. We are fortunate to have such recent, and well done studies that supplement and update Banta's classic work on the Ohio River.

Bigham (1991 and 1998) has focused on the relationship between the river and the economic development of the region more closely than any other scholar and his work is central to understanding the overall economic and community history of the Ohio Valley.

Population growth in the Ohio Valley was explosive. Despite glowing reports on the area's potential, such as that of Lewis Evans, a Philadelphian sent by the governor of Pennsylvania to scout the region in 1750, the geopolitics of mid-eighteenth century North America worked against large-scale settlement. Prior to 1763 the Ohio was controlled by the French who strongly discouraged settlement because it would interfere with the fur trade. There was also a notable lack of French people anxious to settle in North America, but that's another issue. After 1763 when Great Britain took control of the area between the Appalachians and the Mississippi, crown policy was to limit settlement to the eastern side of Appalachians. Thus, the valley was largely unsettled by Europeans at the time of the American Revolution, although its resources were very

well known from the reports of Lewis and British naval officer Thomas Hutchins who conducted a hydrographic study of the river in 1766 and a number of others.

Settlement of the region began once the restrictions of British policy were removed. It received further impetus when the port of New Orleans was permanently opened to American commerce by the Louisiana Purchase and finally Native Americans, who were encouraged to attack American settlers by the British through the early years of the nineteenth century, were defeated by General William Henry Harrison at the Battle of Tippecanoe in 1811.

In the first federal census of 1790, the population of the Ohio Valley was about 125,000. Twenty years later it was around 850,000. Further, the value goods cleared at New Orleans, which were $5 million in 1807, rose to $22 million by 1830. (Bigham, 1991, p. 135-6.) Jakle (1977) points out that in 1800 there were only 10 places in the Ohio Valley with more than 500 residents. By 1850 there were 300, including three with more than 50,000 residents - Cincinnati, Pittsburgh, and Louisville. The river, according to Jakle, was critical. "Towns grew along river routes, especially where people and commodities were exchanged between land and water routes." (p.123)

Critical to the growth of the region was the development of the flatboat trade with New Orleans, which allowed the development of commercial agriculture and commerce. With the access to markets that the Ohio River provided the region quickly moved from subsistence agriculture to commercial farming and the development of commercial houses, banks, and manufacturing, all of which support much larger populations than subsistence agriculture. The development of trade on the river led to the establishment of numerous communities along the river and its tributaries. The river trade stimulated the regional economy in two other significant ways, according to Bigham (1991), the development of a boat-building industry and the movement to improve the river and provide not only safer navigation, but the building of landings, warehouses and other structures. The boat building industry became an important part of the region's growth, not only providing transportation, but by solving transportation problems.

The earliest boats on the river after the canoes of the pioneer period were flat boats. As stated above they could only effectively move down river. An historian of urban development in the region, Allen J. Share (1982) has observed the consequences of "the difficulty of upriver travels during the age of keelboats, flatboats, and barges. The trip up the Mississippi and Ohio rivers from New Orleans to Louisville consumed between three and four months, while the journey from the Falls City to Pittsburgh required an additional month." The difficulties of moving goods upriver established the basic parameters of the region's economy -- locally produced products of all kinds went down river to New Orleans, manufactured goods also came down river through Pittsburgh. Flat boats did not allow direct exchanges between points downstream to points upstream and often required much longer journeys for goods than the simple distance between places - pork from Cincinnati, for example, had to go to New Orleans and then up the coast and overland to Pittsburgh, rather than going the much shorter distance upstream. The keel boat allowed movement both ways on the river, although they were still much more effective going with the river.

The introduction of the steamboat on the western rivers made the river a truly two-way highway and facilitated the integration of the valley's economy. It greatly expanded the potential for commercial agriculture and led communities to build landings and wharves to compete for trade. Steamboats also substantially reduced the time it took to ship goods. By 1838 travel time from Louisville to New Orleans had been cut from four months to six days. By 1860 more tonnage was

moving on the Ohio and Mississippi rivers than was carried by all the registered ships in the British Empire. (Hartley 1959: 15)

The new steamboats were larger than the flat boats and keel boats and began to call attention to the natural obstacles and inefficiencies of Ohio River navigation. The shifting channels, sand bars and snags were now harder to avoid and the seasonal fluctuations in the depth of the river became a serious concern. As the size and scale of the Ohio Valley economy grew and especially after moving large quantities of coal became an important part of that economy in the 1850s these issues became increasingly important and resolving them became more urgent.

The Falls of the Ohio at Louisville had long been recognized as the major obstacle to the free movement of shipping on the river. In a very real sense the Ohio Valley economy had been divided into two economies – the Upper Ohio Valley and the Lower Ohio Valley -- which connected at Louisville. (Jakle 1991: 123) Louisville initially benefited from this as the transshipment point for all shipments on the river. The heavy labor demands for moving goods around the falls created jobs and formed the base for the city economy. Louisville's nickname, The Falls City, reflects the significance of the falls in the city's growth and development. The completion of the Louisville and Portland Canal in 1833, combined with the introduction of the steamboat allowed Louisville to build on its initial advantage and firmly establish itself as the commercial center for the lower Ohio Valley.

Prior to 1850 problems with river navigation offered as many opportunities as they did obstacles for growth because of the generally strong commercial agricultural economy in the Valley. As the demand for coal increased, for example, the difficulties inherent in moving coal barges, which had deeper draft than steamboats during the parts of the year the river was relatively low, provided a strong incentive to develop the coal fields of the lower Ohio Valley in southern Illinois, southwestern Indiana, and far western Kentucky. General manufacturing followed a similar course in the manufacture of machinery and farm equipment. Evansville became an important regional manufacturing center in large part because of the accessibility by water of coal and iron ore.

Growth within the region spurred technological development of river craft and increased the need for improvements in the river. Periods of low water became increasingly problematic for the movement of goods. While the river remained an important, primary transportation method through the 1880s, the railroads began to develop routes that paralleled the river and competed directly for freight.

While Evansville used a packet service to communities on the upper Tennessee River to expand its wholesale trade and foundry operations into the 1920s – many Tennessee River towns have cast iron front buildings inscribed with the names of Evansville foundries -- and the shipbuilding and repair yards at Paducah continue to operate, after 1880 packet service generally declined and the railroad came to the fore as the primary, and dominant, mode of moving goods within the Ohio Valley. Most growth in Louisville, for example, was related to the railroad between the 1880 and World War I. Paducah saw its growth during the same period focus on the railroad bridge across the river and the extensive locomotive and repair shops of the Illinois Central Railroad. Except for Evansville, the Indiana river towns declined in economic importance and population. Communities, like Smithland, Kentucky, a relatively small river town at the confluence of the Tennessee and Cumberland rivers, near the Ohio, declined dramatically when they failed to secure railroad links. Henderson, Kentucky, on the other hand, received a strong boost when it did gain a rail line. (Bigham, 1991, p. 160ff.) The railroad was not affected by

fluctuations in river level, which had emerged as a significant problem as the scale of the economy had grown.

River traffic, of course, did not end, but shifted to a greater proportion of heavy bulk goods while continuing as the primary means of transportation for farm goods where the railroad was not available, or in some isolated cases, where rates heavily favored the river and where local conditions presented no serious obstacles. Call for improvements in river navigation escalated with the formation of the Ohio Valley Improvement Association in 1895 and the Inland Waterways Commission in 1907. Finally, in 1910 Congress authorized a series of lock and dams and a nine foot channel from Pittsburgh to Cairo, which would provide dependable year-round navigation, solving the problem that had given the railroads the opportunity to replace the river as the primary transportation network in the Ohio Valley.

The demands of the First World War on industrial production led to a rediscovery of the benefits of river navigation and increased funding for improvements on the river. While the full benefit of this resurgence were blunted by the economic depression that started in 1929, boat building in Paducah, Kentucky and Jeffersonville, Indiana revived. Commercial towing companies and related construction, maintenance, and repair facilities, became an important part of the Paducah economy and have remained such. (Blagg, p. 14) Several depression era projects, especially the Tennessee Valley Authority's flood control and electric generating activities, established a foundation for future growth in the region that would create new opportunities for community growth and economic development and new challenges for river navigation.

After the Second World War the Ohio Valley enjoyed an economic boom that was based on the low cost of moving bulk goods on the river and the region's low electric power costs, which were due in large part to the same factor. Between 1946 and 1953 some 2500 new industrial plants were built in the Ohio Valley on or near navigable streams, an investment of approximately $5.5 billion. (Bigham 1991:165) Steam electric plants in the region grew because of the advantages of cheap transportation for coal by water from both the Appalachian and lower Ohio fields. The ability to move large quantities of petroleum, coal, sulfur, and other raw materials led to the expansion of the chemical industry, at Calvert City, Kentucky, near Paducah. In 1951 General Electric chose Louisville for the site of its huge Appliance Park plant. One of Louisville's advantages was its ability to receive steel from Pittsburgh by water year round. Alcoa chose Evansville for a major smelter in 1957 due to water transportation and cheap electricity. A number of metal, especially aluminum, fabricating firms have located manufacturing plants facilities along the Ohio in Hancock County, Kentucky for the same reason. While river transportation has not been a major source of direct employment for some time, its indirect impact on employment and thus economic and population growth became more important after World War II, after a period of decline, and remains substantial.

Rather than operating as separate systems, a number of river-truck-rail terminals have been developed to integrate transportation within the region. Tonnage on the river has increased steadily from 34 million in 1940 to 80 million in 1960, 151 million in 1977, and 239.8 in 1997. A narrower range of products are moved on the river, principally coal and coke, but also petroleum products, aggregates, iron and steel, and chemicals. The revival of river traffic has been due to a combination of technological advances -- the diesel tow boat and larger steel barges -- but also to the canalization of the river through a series of locks and dams that has solved the problem of seasonally low water and allows larger tows to operate efficiently year round.

In a report prepared in 1964 for the Kentucky Department of Commerce, Bramlett and Pratt referred to the Ohio as one of the most important resources of the region. They went on to develop this point more fully,

"The reasons for the present growth in river tonnage are straight forward. First, industry migrates to areas where an ample supply of water and low cost power is available, and where the possibility exists for low cost transportation of either raw materials, finished goods, or both. Secondly, the modernization and construction program of the Corps of Engineers on the Ohio River System will permit the handling of bigger equipment at a faster rate and at lower cost to barge traffic. Last, the continuing improvement in the design of tow, barge, and dock equipment [permits more efficient haulage and handling of raw materials by river transportation." (Bramlett and Pratt 1964: 7)

The preceding has offered a "macro" level view of the relationship between improved river navigation and the economic growth of the communities of the lower Ohio Valley with sufficient examples to demonstrate the key role that river navigation played in the economic development of the lower Ohio Valley. There is another useful and potentially critical level of analysis, the "micro," or, specifically in this case, community-level. Communities did not benefit uniformly or automatically from improvements in river navigation. Because of location, existing industry, enhancements to river traffic, and local entrepreneurship some communities made more of the opportunities improved river navigation offered. Initial advantage is an important factor in community growth and economic development and to a certain extent acts as conservative, inertial factor.

Louisville, for example, has remained an important regional center through a succession of changes in the place of river navigation in the regional economy and appearance of other modes of transportation, some quite different from river navigation. United Parcel Service has established its major air freight service hub at the Louisville airport at least in part because of the ability to use river barges to transport jet fuel. Conversely, Cairo has remained a minor city, that struggles with a broad range of social and economic problems, despite the potential its location has offered throughout its history. While the "big picture" provides an important and necessary perspective for local development, the full impact improvements in river navigation in the Ohio Valley can only be fully understood if we look at the local level.

Along the 381 miles of river between Louisville, with a 1990 population of just under 270,00 and Cairo with fewer than 5,000 there are a range of communities. Each community has its own history of interaction with the river and its own particular insight to offer.

Louisville was founded in 1779 on the south bank of the Ohio River opposite the Falls of the Ohio. Its early growth was slow in large part because its hinterland was slow to develop due to problems with Native Americans, who were encouraged by the British in the Great Lakes area to attack settlers, thus protecting the fur trade. The potential of Louisville's location was clear. In 1783 the Commonwealth of Virginia designated it as a Port of Entry. In 1799 the federal government made the same designation. In 1800 Louisville had a population of only 359 and very little trade or commercial activity due to the limited growth of its potential hinterland. It was a regional center for the distribution of goods brought up from New Orleans and for assembling cargoes for shipment to New Orleans, but its hinterland population was so small and scattered that Louisville remained very small. In 1810 its population was 1357, a sizable increase since 1810, but still a very small community.

Two events in 1811, however, opened the way for Louisville to become the leading city in the lower Ohio Valley. The first was William Henry Harrison's victory over the Shawnee at Tippecanoe, the beginning of the end of British-inspired Indian problems for settlers in the Ohio Valley. Harrison completed the opening of the Ohio Valley to large scale settlement with his victory over Tecumseh at the Thames in 1813. The second important event was the first steamboat trip on the Mississippi and Ohio rivers by the *New Orleans*. The 1815 voyage of the *Enterprise* from New Orleans to Louisville in twenty-five days made the potential of steamboats clear. By 1817 the *Washington* had completed a round trip between New Orleans and Louisville in forty-five days. Alan Share points out the significance of steamboats for the Ohio Valley region, "By slashing distances and travel time, steam navigation transformed the Ohio Valley into a settled and cultivated region in a single generation. A northward and eastward movement of goods came to supplement downriver commerce, as steamboats and a series of canals constructed in the 1820s and 1830s connected the Ohio Valley to the Great Lakes and the Atlantic seaboard." (Share 1982: 31)

Louisville quickly became the focal point for the now rapidly expanding two-way trade between Pittsburgh and New Orleans, and all points in between, because the falls remained an obstacle to navigation. With the increase in commercial activity and river shipping came increased demand for a way around the falls. Louisville was a "break bulk" point for all cargoes. As Conrod (1976) discusses, such "break-in-transit" points require many services, such as men and equipment to move goods, warehouses and other storage facilities, hotels and restaurants, and offices to coordinate the transfer of cargoes. All of these activities create entrepreneurial opportunities and economic opportunities.

Early industrial development in Louisville was closely related to river navigation and the Falls City's place as a break-in navigation. In 1853 *DeBow's Review* succinctly summarized the important role the falls had played in Louisville early growth, "The falls in the Ohio River arrested the course of navigation, and made the stoppage necessary. This stoppage produced commercial wants – commercial wants, a city." Shipbuilding and equipping riverboats were among the first industries to develop, followed quickly by iron foundries and steam engine fabricators. In 1812 John Skidmore established the first iron foundry in Louisville and five years later Thomas W. Bakewell and David Prentice began manufacturing steam engines. These were joined quickly by flour mils and a distillery to process, in very different ways, the grain crop of the emerging city's hinterland. By 1815 the river traffic had led to the establishment of four rope walks and a like number of soap factories, two tobacco manufactories, a steam saw mill, and a stoneware factory.

In 1825 the Louisville and Portland Canal Company was incorporated and the company completed a canal around the Falls of the Ohio in 1833. While the canal made it possible to avoid the added expense of transferring goods from one ship to another, Louisville's economic growth accelerated and its population doubled between 1830 and 1840 and again between 1840 and 1850 to 43,194. Louisville became the regional metropolis for the lower Ohio Valley because of its location on the Ohio River during the period when river navigation was the only economically viable mode of transportation for the region's products.

Two things helped fuel Louisville's growth and rise to regional dominance, both of which were closely tied to river navigation. One was the expansion of established industries directly related to river navigation such as manufacturing steam engines, boat building, and servicing and supplying the river industry. The second was processing the agricultural produce of its hinterland and shipping it out into the national market. As improvements in navigation made it possible to ship goods more cheaply to market, population and agricultural products increased in the hinterlands

of Louisville, creating more opportunity for industrial growth in processing these products. Distilling, milling, tobacco and hemp processing, and food processing developed and expanded. An outgrowth of the forges and other metal factories was the development in Louisville of a stove industry. By the 1850s the Ohio Valley led the nation in the production of pork products – Cincinnati was known as Porkopolis – flour, liquor, lumber, and agricultural machinery. Louisville was a major producer of hemp rope and tobacco products. All of this was made possible by river navigation.

With the tremendous increase in commercial and industrial activity the river became a focal point of the economy and as Kreipke points out the volume of traffic on the Ohio, especially west of Louisville was dependent on the depth of water in the river and the depth fluctuated seasonally during the year. Low water made stretches of the river more hazardous, slowing and at times stopping traffic or forcing boats to carry less than a full cargo to reduce their draft. The economic impact of the depth of the river was so great that it became a matter of public attention, with the rise and fall of the river being regularly reported. In 1854 a Louisville editor wrote that the low level of the river would reduce fall trade by one-third. Louisville's business and community leaders supported river transportation improvement projects to resolve the problems caused by fluctuations in the river level. They also supported the development of packet lines on the Ohio's tributaries and more importantly for the long term future of Louisville railroads. According to Share they did not see the railroad replacing the river entirely, but rather "they perceived the beginning of a new era in river navigation in which fast packet boats would play a major role, making frequent trips on tributary waterways and serving as feeders to the railroads." (Share 1982: 67)

Louisville's growth between 1880 and the First World War was due to its rail connections rather than the river, continuing a trend that had begun in 1856 when tonnage carried by steamboats had begun to decline. (Bigham, 1991) Towboats and barges, however, continued to carry very bulky cargoes on the river and it remained an important part of the region's transportation system. The First World War refocused attention on the benefits and advantages of river navigation. After 1930 there was a resurgence in river shipping and the construction of new facilities that connected barge, rail, and truck traffic into a coherent system. The truck-barge terminal in Louisville was the last such facility moving downstream from Pittsburgh. In 1951, as mentioned earlier, General Electric located its Appliance park, a large, state-of-the art facility in Louisville because of the availability of year-round water transportation for steel from Pittsburgh to Louisville. More recently United Parcel Service chose Louisville as its major air hub because of the availability of river shipping for jet fuel.

The first large commercial center moving downriver from Louisville is Owensboro, Kentucky. The first permanent settlement at what had been called Yellow Banks by travelers on the Ohio River was in the late 1790s by William Smeathers (sometimes spelled Smothers). In 1816 community was platted and formally surveyed. The legislature named it Owensboro after Col. Abraham Owen, who died at the Battle of Tippecanoe. (Kentucky Encyclopedia, p. 700.)

Prior to the Civil War Owensboro was principally a commercial center for a rich agricultural hinterland. James Roger established the first tobacco warehouse in the city in 1837. Several others followed quickly and there were at least five operating in 1860. Following the War Owensboro became a major tobacco processing and shipping center for Green River tobacco. Humphrey's 1883 history of Daviess County lists eighteen firms established after the war and still active when he wrote. Most of the tobacco processed in Owensboro was stemmed and packed in hogsheads for shipment to London and Liverpool, with the lower grades of leaf intended for the German market. (Humphrey 1883: 336-340)

During the 1880s a number of distilleries were established in the city. Humphrey notes the very important role river shipping played in the development of this industry. "Distilleries existed here in a very early day, but it is only within the last few years that the business has increased by anything like its present proportions. There are at present [1883] eighteen distilleries within the county. With few exceptions more grain is grown here than in any other county in the State. This fact accounts for the abundance of and cheapness of material. The Ohio River furnishes shipping facilities of an unequaled character, and the railroad running south from Owensboro is always ready to carry freight on reasonable terms. It is mainly for these reasons that the large distilling business of the county has been carried on so successfully, while it has languished and died in other sections of the country." (Humphrey 1883: 341) Humphrey goes on to identify and describe briefly the eighteen distilling firms operating in Daviess County.

Humphrey describes a number of other industries and individual firms. Wagon manufacturing and the manufacture of parts for horse-drawn vehicles was well represented by a number of firms, including Troutman, Rarick & Co., John J. Hill's Hub and Spoke Factory, Owensboro Wheel Company, Southern Wheel and Handle Company. There were several furniture and wood products firms, including J. G. Delker, Manufacturer of Furniture and Chairs; John R. Osborne & Son's Planing-Mill; and J. H. Taylor's Planing-Mill. The Owensboro Foundry, doing business as Guthrie, Long & Bransford, had been established in 1868. There were also several flour mills, brickyards, and a cigar manufacturer. Most directly related to river transportation were the People's Wharf-Boat and Transfer Company, organized around 1869; the Owensboro and Rockport Transfer Company, incorporated in 1882; and the Steam Ferry Company formed in 1882. (Humphrey 1883: 345-351)

One of the most prominent of Owensboro's industrial fiirms, the Owensboro Wagon Company was organized in 1883 and remained in business for sixty eight years, producing 6,000 wagons a year at its peak. For a time it was the largest business in the city and nationally known for its quality products. As the automobile replaced the horse the firm shifted to producing truck bodies. (Potter 1965: 35)

By the 1890s Owensboro had become a diverse industrial center with wagon and buggy companies, foundries, brick and clay plants, as well as tobacco factories ands distilleries. The river was an important part in the city's economic base. "Three railroads linked it to markets, and numerous packet lines offered connections by water. The towing industry opened opportunities for shipping grain and coal to markets throughout the Ohio and Mississippi systems." (Kentucky Encyclopedia, p. 700-701.)

During the first half of the twentieth century Owensboro grew to be the third largest city in Kentucky, due to its diverse industrial economy. The largest employer in Owensboro was Ken-Rad a firm that began in the late nineteenth century as a light bulb manufacturer and moved into vacuum tubes for radios and televisions. By the 1960s Ken-Rad, which had been sold to General Electric in 1945, employed more than 6,000 people. Owensboro's diverse industrial sector included a number of industries that centered on the river and the availability of inexpensive water transportation for their raw materials and finished products. One such firm was the Owensboro River Sand and Gravel Company, organized in 1914. They used dredges to pump river sand into barges, which were floated to Owensboro and unloaded. Later the firm developed a river-rail terminal for loading and unloading steel and other bulky, heavy goods. They also opened a quarry in Meade County and shipped crushed lime by barge to Owensboro for processing by the Owensboro Concrete Company. Throughout its development, river shipping has been central to the firm's success. (Potter 1965: 36) Other industries that operated in

Owensboro during the first half of the century were meat packing, grain shipping and processing, steel, chemicals, plastics, electronics, and the long-established distilling and tobacco industries.

During the 1970s manufacturing in Owensboro declined and the city's economy came to be dominated more by service industries. The river, however, has continued to play an important role in the city's economy. "[T]he development of the Owensboro Riverport enabled many industrial shippers to operate their own barge-loading facilities, capitalizing on the city's primary transportation resource, the Ohio River." (Kentucky Encyclopedia, p. 701.) Processing and shipping soybeans and corn by rail and barge is a major industry in Owensboro today. Tobacco remains important through the Pinkerton Tobacco Company, the Field Packing Company, established in 1914, continues the meat packing industry in the city, and the Glenmore Distillery Company still operates.

The second largest city in the lower Ohio Valley for most of its history has been Evansville, Indiana. Col. Hugh McGary, Jr. founded Evansville in 1812. The first plat for the community was done in 1814, but it was replatted in 1817 and incorporated as a village in 1819, one year after it had been named county seat of Vanderburgh County. Evansville is located on a sharp bend in the Ohio River nine miles below the confluence of the Green River with the Ohio and about half way between Louisville and Cairo. The bend in the river combined with Pigeon Creek to give Evansville an excellent harbor. The Green River, and several navigable tributary streams, flowed generally north through land in Kentucky that was both rich agriculturally and a major coal field. In 1836 Evansville was a terminus for the Wabash and Erie Canal. In 1847 it was chartered as a city.

By 1847 Evansville was an important port on the Ohio, the most important between Louisville and Cairo, serving as the major commercial and trading center for the Green, Barren, Cumberland, Tennessee, and Wabash river valleys in southwestern Indiana and western Kentucky. Evansville served as the major transshipment point for cargoes going between the Ohio-Mississippi river system to the smaller western tributaries of the Ohio, the Green, Barren, Cumberland and Tennessee rivers in Kentucky and the Wabash and the White in Indiana. Large amounts of corn, oats, wheat, hay, pork, bacon, tobacco, and potatoes from those areas moved south from Evansville. Between 1848 and 1852 a 2000 foot wharf was constructed to accommodate the city's commerce. (Conrod, 196) It also benefited from a railroad connection with Terre Haute, which was in operation by 1854.

As in the case of Louisville the commercial activity generated by river shipping led to the early development of industry. The river allowed the movement of raw materials to Evansville and the shipment of finished goods out along the same trade routes used in moving agricultural products. Flour milling and tobacco processing, lumber and wood products, including furniture manufacture developed in Evansville as large scale industries, as fairly direct outgrowths of its river commerce. Foundries and machine shops, another large-scale industry in nineteenth-century Evansville, grew out of the needs of the river industry itself. The most interesting of Evansville's early industries in terms of the importance of river navigation was cotton processing. The boats that took the agricultural and manufactured products of Evansville returned with cotton that was spun and woven in the city. Slaughtering and meat packing, brewing, clothing manufacture, and carriage and wagon making were other important industries in nineteenth-century Evansville. Like other river cities the railroad became more important in economic development after the Civil War. However, Evansville sustained a regular packet service along the Green, Tennessee, and Cumberland rivers, areas that did not see railroad development until later.

During the Second World War, the Missouri Bridge and Iron Company built LSTs in Evansville and employed 19,500. Their subcontracts with twenty-seven local firms, many of who traced back to the industrial beginnings of Evansville, and other defense work totaled $300 million. (Bigham 1991:164.) In 1957 Alcoa established a major smelting facility at Evansville to take advantage of the water transportation offered by the river and also the region's inexpensive electric rates, which are due to a considerable extent to the ability of power generators to use coal from Appalachia and the coal fields of the lower Ohio Valley that can be cheaply transported by water.

Across the Ohio from Evansville is Henderson, Kentucky. Henderson was founded in 1797 on the site of an earlier settlement know as Red Banks, which had been established in 1791. Slightly down river from the confluence of the Green and Ohio rivers, the community was named for Col. Richard Henderson, promoter of the Transylvania Company, who had obtained a land grant to the area from the Virginia Assembly in 1778.

Very early in its history Henderson emerged as an important river port, its location on a bluff, above the flood plain, gave it an advantage over other Kentucky river towns that were periodically flooded. In 1810 the community achieved legal status as a city. Among the community's businessmen in this early period was general store keeper John J. Audubon. The steamboat *New Orleans* called at Henderson on its historic voyage on the Ohio. By 1814 a tobacco warehouse had been built in Henderson and the connection between the river and the city's industrial development firmly established. Arnett describes the relationship in a straightforward manner.

"For the first 90 years, Henderson industry was dependent on the river: dams on the Green made that river navigable on a year-round basis, but the summer droughts limited the use of the Ohio to shallow-draft vessels. This became especially critical after 1811 when steamboats came into use. A jetty dam was built south of Henderson which resulted in the loss of several hundred acres of fertile farm land, with little success in deepening the stream.

"Except for industries that catered to local needs, e.g. lumber and grist mills and blacksmiths, the two products made for export were tobacco and distilled liquor. These could be held in storage until the river was navigable." (Arnett 1976: 170)

The arrival of railroads in Henderson, specifically the Evansville, Henderson & Nashville in 1869 (connecting to Nashville in 1871) and the Louisville, St. Louis & Texas in 1889, and the construction of a railroad bridge across the Ohio in 1885 made year-round shipping possible. (Kentucky Encyclopedia: 423) The city had eighteen tobacco factories by the early 1890s with another thirty-three in the county shipping over 12 million pounds of dark tobacco each year. By the early 1920s this had risen to 40 million pounds. (Arnett 1976: 170) Few of these "factories" did more than ship tobacco. Among the exceptions were Robards-Kitchell Manufacturing Company (later J. D. Robards & Co.) which made Greenville brand chewing tobacco starting in 1883 and The Hodge Tobacco Manufactory (1884), and later the Reichert Cigar Factory. The Henderson Tobacco Extraction Works made insecticide from nicotine extracted from waste tobacco. In 1911, it was incorporated as the American Nicotine Company. (Arnett 1976:171)

Early farmers in the area made grape wine and fruit brandy and a Mr. Melton was making and shipping out via the Ohio River twenty-five gallons of fruit brandies a year before the Civil War. (Starling 1887: 517) Shortly after the War, D. R. Burbank built the first whisky distillery in Henderson. In 1872 Starling & McClain established a second distillery. In 1880 W. A. Winstead and N. B. Hill began distilling whisky as Hill & Winstead and their Silk Velvet Whisky was

produced just before World War I. A third major distilling business in Henderson was the E. W. Worsham Company, later known as the Kentucky Peerless Distilling Company, established in 1881 by E.W. Worsham and J.B. Johnson. Peerless Distilling was an extensive operation with three large aging houses, a cooper shop and barrel storage building, and grain bins. Their Peerless brand whisky stopped production to save corn during World War I and never reopened due to prohibition. The last of the large scale Henderson distilleries was Wither, Dade, & Co., established in 1881 by J. E. Withers, H. F. Dade, and Capt. Charles G. Perkins.

The Henderson Brewery opened before the Civil War and operated until prohibition, except between 1885 and 1887. Efforts to reopen in1933 were thwarted by extensive vandalism to the plant while it was closed. (Arnett 1976:171)

Another nineteenth-century industry that depended to a considerable extent on river transportation was the Henderson Coal and Mining Company, incorporated in 1875 to develop coal reserves in the Green River area. In 1882 it was renamed the Henderson Mining and Manufacturing Company and built an ice plant adjacent to the mine.

Other industries developed primarily to serve local markets, but all used the river to some extent to move raw materials in and finished product out. Data from the nineteenth century does not allow a neat distinction between river and rail as the means of transit. There were two textile mills, one woolen and one cotton, in Henderson during the nineteenth century. The Henderson Woolen Mill was incorporated in 1882 and in 1886 began producing ready-to-wear pants, known as "Kentucky Jeans." The Henderson Cotton Mills, organized in 1883, was the city's largest industry in the late nineteenth century. In 1922 it was sold and continued as part of Consolidate Textile Corporation, it operated until 1931.

Henderson was also a center for manufacturing horse-drawn vehicles. George Delker Company began making buggies in 1863. The Henderson Buggy Company was organized in 1882. A 1913 city directory listed these two and Delker Brothers and the Park Carriage Company. While the automobile essentially ended the horse-drawn vehicle industry, Delker Brothers converted to manufacturing furniture and lasted until the 1970s. The Henderson Wagon Works building was acquired by H. J. Heinz, but the tomato cannery they established was short lived. (Arnett 1976:173)

The period 1916-1937 was hard on Henderson. The rise of the automobile closed its vehicle plants and prohibition did the same for its distilleries and brewery. The tobacco market, its last "export" industry was hard hit by changes in the international market. Henderson County lost population between 1900 and 1930, falling from 33,000 to 26,295.

The revival of industry in Henderson after 1937 was related to the Ohio River, but to flooding as much as navigation. Henderson was the only major community between Louisville and Cairo that did not experience major flooding in 1937. A Board of Trade was established in 1938 and its Industrial Committee began to rebuild the city's industrial base which had shrunk significantly. During World War II the Atmospheric Nitrogen Corporation built a plant in Henderson. In 1950 the plant was acquired by Spencer Chemical Company and began producing agricultural and industrial chemicals. The inexpensive transportation for bulky goods was a key factor in the plants establishment. By 1950 it had a payroll of $1.4 million., but the plant was closed and its operations moved to Louisiana when it was acquired. The Agrico Chemical Company came to Henderson to make fertilizer for the same reason - availability of low cost water transportation. More recently the city and county have stressed development of a riverport as a central factor in

their economic development strategy, which attracted several in large firms including Anaconda Aluminum and Firestone Steel Products. (Arnett 1976: 176-177.)

Paducah, Kentucky is another Ohio Valley community whose growth and economic development have been strongly shaped by he river. Paducah is located at the confluence of the Tennessee and Ohio Rivers and near the confluence of the Cumberland with the Tennessee and the Ohio with the Mississippi. The potential of the site was recognized early on and George Rogers Clark claimed the site in September of 1795. Problems with access to the land, which was west of the territories purchased from Indians delayed settlement. The Jackson Purchase in 1818 opened the land for settlement. Clark's brother, William (the Clark of Lewis and Clark), took up the project of developing the site. A town was platted on June 18, 1830 and named Pekin. The federal census that year recorded 105 residents. The name of the small community was soon changed to Paducah, after a legendary Indian chief. Paducah's initial development was almost entirely related to its role as a river town, only slowly developing industry that was not related, directly or indirectly to the river. The river-related industries that did develop, did so very quickly. Shipbuilding and boat repair yards sprang up and encouraged the development of the second wave of industries in Paducah – iron foundries, rope and cordage factories, and lumber mills. By 1850 Paducah prospered handling the agricultural produce of its hinterland, principally tobacco, flour and meal, strawberries, livestock, and wood products including sawn lumber, railroad ties, and barrel staves. Little processing of these products was done in Paducah. These diverse and rapidly growing industries attracted many people to Paducah, including German and Jewish immigrants. By 1850 Paducah's population was 2,428 twenty times what it had been in 1830. (McCracken County: 15.)

Paducah served as an entrepot for cargoes moving along the Ohio River for communities on the Tennessee and Cumberland rivers. The larger steamboats that operated on the Ohio preferred to drop cargoes for communities on the tributaries at a convenient port on the main channel rather than sail up and down the smaller streams. This helped Paducah dominate Smithland, an early rival, that began as an entrepot to serve the Cumberland River. Initially, Paducah's complementary area was limited the Tennessee River, with Smithland, which is located at the confluence of the Cumberland and the Tennessee, performing the same function for the Cumberland. Within five years of its founding work had begun on docks and other improvements along the river. Throughout its history Paducah has served as commercial and wholesale grocery center for a substantial region in southern Illinois and far western Kentucky. By 1860 the wholesale grocery trade exceeded a million dollars. (McCracken County:15.) This region, however, has long been very poor and Paducah did not gain as much advantage from its role as cities with economically more vibrant hinterlands.

The Civil War disrupted economic development in Paducah. The same location that had fueled Paducah's rapid growth before the War made it a strategic location during the War. The Union Army, under General U.S. Grant occupied Paducah at the beginning of September 1861 and Federal troops remained in the city throughout the War. Because Paducah's economic orientation before the war had been strongly to the South, there were strong pro-Confederate tendencies in the city, especially among its business and commercial community. A number of Paducahans were arrested during the War for sedition or other crimes and many were forced to relocate.

Following the War the city pursued a conscious strategy of industrial development under the leadership of Mayor Meyer Weil, a German Jewish immigrant. (McCracken County: 15.) The transportation advantages afforded by the Ohio and its tributaries were central to this strategy. Packet services based in Paducah moved people and goods on the rivers and the city emerged as a

major shipbuilding center, with about a third of its workforce working in the industry. (McCracken County: 16.)

Throughout the nineteenth century Paducah competed unsuccessfully with Evansville for regional supremacy. The railroads contributed a great deal to Paducah's development in the second half of the nineteenth century. The first rail lines to reach Paducah were north south lines, the first the Mobile and Ohio, followed by a Nashville to the Ohio River line and the Illinois Central. Paducah emerged as a major railroad repair center and the Illinois Central locomotive shop, the third largest in the world, was the community's largest industry for several generations before it closed in the early 1950s when diesel locomotives replaced steam. While the railroad assumed a more visible role in Paducah's economy in the first few decades of the twentieth century, river industries remained an important foundation for the local economy and became increasingly important within the regional economy.

Paducah has perhaps benefited more from the revived awareness of the importance of river navigation after World War II. Just as the Illinois Central locomotive shop was closing, Paducah was chosen as one of two sites, the second also in the Ohio Valley at Portsmouth, Ohio, for a major nuclear facility, a gaseous diffusion plant to produce high grade uranium and plutonium. One important reason why Paducah was chosen was the good river transportation the city enjoyed. Another, the availability of low cost electricity is in large part due to river transportation as well. The nuclear plant attracted a large workforce and helped fuel a doubling of Paducah and McCracken county's population. (McCracken County: 17.)

Calvert City, Kentucky, just upstream from Paducah in McCracken County, is an outstanding example of the importance of river navigation in industrial development. A large number of chemical plants have located along the river to take advantage of the inexpensive transportation for their bulky raw materials and finished products as well as the region's low electric rates.

Paducah has become a major service center for the river barge industry in the last fifty years due to its location near the center of the Ohio-Mississippi system. In recent years the Seamen's Institute of New York established a river navigation safety training institute in the city and has sponsored a River Heritage Museum to highlight the city's long term relationship with the river.

The last important commercial and manufacturing center on the Ohio River is Cairo, Illinois. Cairo is located at the confluence of the Ohio and the Mississippi. In 1856 amid predictions that Cairo would soon surpass St. Louis, Louisville, and Cincinnati it was proclaimed the Pittsburgh of the west. Lantz points out that "Speculators we impressed with the fact that Cairo lay at the head of large steamboat navigation, usable in summer and winter, at the point where Missouri, Kentucky, and Illinois come together. The developers saw tremendous possibilities for a transshipment point there. The belief that these conditions would sustain Cairo's growth was reiterated time and time again. (Lantz 1972: 7)

Comeaux makes the same point, slightly more generally, when he identifies the two great themes in Cairo's history as first, its potential as an entrepot, a promising point for the gathering and dispersal of goods, and second, its potential as a gateway connecting North and South along the Mississippi and Ohio rivers. (Comeaux 1966:19)

There were several unsuccessful efforts to settle the site of Cairo beginning in 1702. George Rogers Clark visited the site in 1779 but rejected it a location for a fort due to its being "Often ten feet under water. He built Fort Jefferson on the bluff across the river near present-day Wickliffe, Kentucky instead. In 1818 an Act of Incorporation was passed but little was done beyond drawing

up a plat map. In the late 1830s the Cairo City and Canal Company was formed to build a city and a canal connecting the Cache River with Cairo. Initially successful, the community had a population of about 2,000 in 1840 and supplied many passing steamboats with firewood and other supplies. However, problems with flooding and the companies reluctance to build levees or sell, rather than lease, land brought on a severe crisis. By 1845 there were only 113 people in Cairo and the next year the Cairo Property Trust acquired the city. Much of Cairo's economic activity took place on wharf boats rather than on land because of the frequency of flooding. Charles Dickens passed through Cairo and provided a highly negative description of the city and its population in his *American Notes*. (Lantz 1972:14, 12) The population stood at only 242 in 1850.

Prior to 1856 when the Illinois Central Railroad was completed to Cairo, the city's economy was almost entirely dependent on river traffic. Such traffic was sporadic because there was little economic activity in Cairo's hinterland to create cargoes going out or demand for goods coming in. If there were no passengers for Cairo or no need for firewood or other supplies, boats simply steamed by. Conditions upstream or downstream also affected shipping volume, making it highly erratic. While there were efforts to develop a packet service and establish Cairo as a regional transshipment point, they were largely unsuccessful due to the low level of economic activity in the immediate area.

The arrival of the Illinois Central Railroad, which had selected Cairo as its southern terminus, in 1856 opened up opportunities for Cairo by combining rail and river transportation. The upsurge in activity was dramatic. "Just prior to the Civil War, about a hundred steamers per week were reported. There were about two hundred people a week arriving at the St. Charles Hotel, a good hotel by all standards. The freight office showed a business of $430,780.18 for 1860, a freight business of $200,000 was reported for a single month. The Cairo City Mill was turning out 12,000 to 20,000 feet of lumber a day. Business houses were going up rapidly. The depot was reported as loaded with 180 freight cars. By 1860 there was a total population of 2,188." (Lantz 1972: 25) The newly prosperous city had a flour mill, a whisky distillery, several slaughter houses, eight hotels, a foundry and machine shop three newspapers, several wholesale grocers, a number of forwarding houses, and a railroad depot.

The coming of the Civil War had a tremendous impact on Cairo. The city's position at the confluence of the Ohio and Mississippi and as the southern terminus of the Illinois Central made is a very strategic location. Large numbers of Federal troops were dispatched to Cairo as part of the plans for the defense of St. Louis. It was U.S. Grant's headquarters, with more than 10,000 troops, by the summer of 1861 and the base for the U.S. Army's Western Flotilla for the balance of the War. (Merrill 1983) Business improved dramatically during the early days of the war, especially in those businesses related to supplying troops or fitting out naval boats. Civilian business, however, declined as the War blocked movement on the Mississippi and disrupted trade to and from the South that had been one of Cairo's strengths. The wartime boom brought many people to Cairo, including many African Americans fleeing slavery. At the end of the war the City's population stood at 8,569, including 2,083 African Americans.

Immediately after the War there was a brief recession in Cairo because of the economic devastation the War had wrought in the South limited trade with the region. Cairo briefly declined in population to 6,267 in 1870. Other railroads made Cairo their Ohio or Mississippi river terminus, however, and the future for Cairo looked bright as a major transfer point for rail and river transportation. In 1880 the city's population reached 9,011.

Ferrying rail cars and whole trains across the rivers provided a solid economic base for Cairo. Other industries developed in Cairo after the War, the most important of which was lumber and

wood products. In 1870 there were eight lumber mills with 155 employees, in 1880 there were 10 in Alexander County with 146 employees. In 1881 Singer Sewing Machine opened a factory with 150 men to build sewing machine cabinets. By 1893 thirty-two manufacturers of wood products employed more than 1000. The Cairo Property Trust, which still owned the waterfront and a good part of the city, levied no charge for unloading logs or raw lumber. There were however high charges for loading finished products onto barges – the Property Trust has close ties to the New York Central Railroad – and most finished products left by rail. Lumber-related industries in Cairo began to decline after 1900 as supplies of raw materials – the logs that had been "towed" from within a 150 mile radius -- in the region began to decline. Flour milling was another industry that prospered in Cairo between the end of the Civil War and 1900.

The economic base of Cairo in the late nineteenth century remained, however, ferrying rail cars and whole trains and transshipping goods from river barges to rail. In 1887 four transfer steamers worked out of Cairo and there were seven railway transfer inclines. The completion of a railroad bridge across the Ohio in 1889 began the decline of Cairo, which was accelerated by the completion of a bridge across the Mississippi at Thebes in 1905. Railroad employment in Cairo declined dramatically after 1890, as did the city's economy.

Early twentieth-century efforts to revitalize Cairo's economy emphasized its location at the break of winter navigation and its fine harbor. They were, however, largely unsuccessful because of the shortage of land not susceptible to flooding. When the river warehouse district experienced a major fire in the 1940s the city was very slow to rebuild and river traffic went elsewhere, especially to Paducah. (Lantz 1972: 46.) While greatly reduced in scale and importance within the region, river-related industries remained important to the local economy in Cairo through firms such as Cairo Marine Service, Waterfront Services, Inc., and Cairo Terminal and Floating Company.

These "micro" examples of case studies of the development of the larger cities in the lower Ohio Valley show clearly that the river and navigation on the Ohio River have played a critical role in their development. In every case choice of location was related to navigation considerations. A break in navigation, as in the case of Louisville, or the confluence of tributary streams in the others being the main reason. When river transportation was the only effective, or cost-effective, means of transporting goods those places that could efficiently accumulate and distribute cargoes enjoyed significant advantages. The urban hierarchy established during the period when the river was the region's transportation link with the world has been remarkably persistent, although no more than geographical theory would suggest – initial advantage is a very significant factor. In the case of the Ohio Valley it is reinforced by the tendency to design the earliest railroads to provide access to the river, thus making the major early river towns also those with the earliest railroad links.

The early industrial development of most communities in the Ohio Valley, from Pittsburgh to Cairo, is linked with access to the inexpensive transportation the river provided. While the railroad replaced the river for a time, the highways that have largely replaced the railroad have actually set the stage for a revival of river trade, within a narrower range of products to be sure, but a revival none the less, since the 1930s. Much of the large-scale industrial development of the lower Ohio Valley since World War II is due to two factors – first and foremost the ability to move bulky raw materials and finished products cost-effectively; second and closely related the region, especially Kentucky, enjoys exceptionally low electric rates due to TVA and the availability of large quantities of low cost coal, shipped by water from the eastern and western Kentucky and West Virginia coal fields, and earlier from coals fields in Pennsylvania. This has allowed the region to develop significant chemical, aluminum, steel, and nuclear industries. The

river which made the area viable for its earliest settlers remains a solid base for its future economy.

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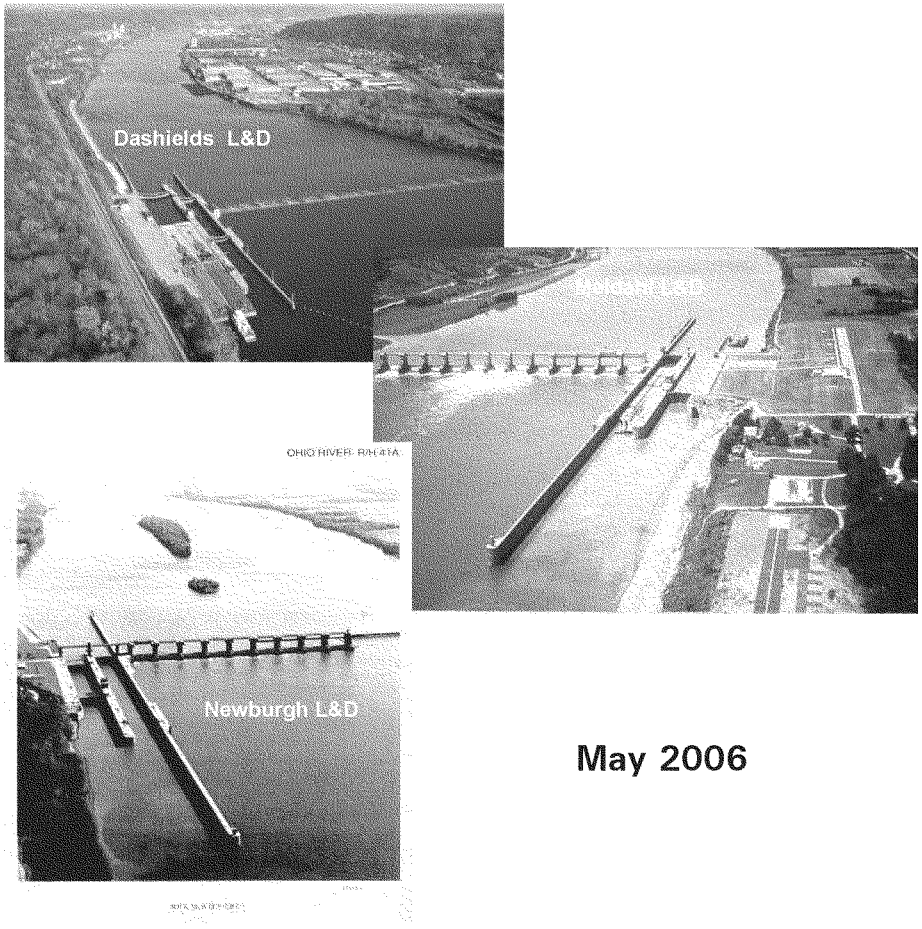
US Army Corps
of Engineers
Great Lakes and Ohio River Division
LOUISVILLE DISTRICT / HUNTINGTON DISTRICT / PITTSBURGH DISTRICT

Ohio River Mainstem Systems Study (ORMSS)

System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

COMMUNICATIONS APPENDIX



May 2006

DEPARTMENT OF THE ARMY
U.S. ARMY ENGINEER DISTRICT, LOUISVILLE
CORPS OF ENGINEERS
P.O. BOX 59
LOUISVILLE, KENTUCKY 40201-0059

System Investment Plan/Programmatic Environmental Impact Statement

ILLINOIS, INDIANA, KENTUCKY, OHIO, PENNSYLVANIA, and WEST VIRGINIA

Communications Appendix

May 2006

Section 1
INTRODUCTION

Communications with the public, the scientific community, and with waterway users and stakeholders has been a major effort throughout this study. The Ohio River navigation system affects many stakeholders and millions of people in the basin. Therefore, communication concerning any proposed change and the process leading to the change are vital for any project to be accepted and implemented. This is the first time that a study of the entire Ohio River Mainstem as a system has been attempted, and because of this, much of the analysis contained in this study is state-of-the-art. Throughout the study, the sharing of information as it has been developed has been an important component of the study process. It provided the Corps the opportunity to share analysis tools developed for this study with others, as well as keeping various interested groups informed as to the progress of the study. The communications process started through public meetings and the workings of interagency groups, was furthered through presentations to groups representing environmental, navigation, and economics interests, and culminates with the publication of this report. The purpose of this appendix is to summarize the communications efforts that have been a part of this study.

Section 2
MYERS/GREENUP L/D FEASIBILITY STUDY

2.1 SCOPING

Ohio River Mainstem System Study (ORMSS) public workshops were held in November 1998 in three metropolitan areas representing the lower, middle and upper reaches of the Ohio River. Three nearly identical workshops took place from 12:00 noon to 8:00 p.m. within a one-week period. These meetings were held in Evansville, Indiana on November 17, 1998; in Huntington, WV on November 19; and in Pittsburgh, PA on November 24, 1998. There were two primary purposes for these workshops:

- To obtain input from the public-at-large on future needs for Ohio River navigation and for environmental restoration opportunities along the River; and
- To fulfill (partially) requirements of the National Environmental Policy Act whichcall for such public scoping meetings.

Each workshop occurred from 12:00 pm to 8:00 pm. Each meeting had a sign-in area, three kiosks (Plan Formulation/Engineering, Economics, and Environmental), and an area closed off somewhat from the main meeting area where a looping slide show developed by the Louisville District was run continuously. There were also table and

chair arrangements set up to supplement the kiosks to facilitate discussions among participants and Corps staff. Corps staffing at each meeting was limited to the Production Team Leaders, Project Manager, and up to one support staff from the host district from Plan Formulation, Economic, Engineering, Project Management, and Public Affairs. Attendance at each of the three meetings were as follows: Evansville – 21, Huntington – 27, and Pittsburgh – 32.

2.2 NOTICE OF INTENT

The Notice of Intent (NOI) was published in the Federal Register on Wednesday October 21, 1998. A similar Public Notice announcing the 3 scoping meetings was mailed to approximately 3,700 agencies, industries and individuals. Comments from letters received regarding the NOI were addressed in the Draft EIS. One comment letter was received from a federal agency.

2.3 PUBLIC MEETINGS

The Corps of Engineers held two public meetings following preparation of the Draft EIS. The first was held at (public workshop about the draft EIS) in the Greenup Co. Ky. High School on the evening of February 9, 2000. The purpose of the workshop was to provide information about the proposed Greenup and Myers lock extension projects. Members of the local community and agencies attended the workshop. A formal presentation about the proposed projects was delivered by Col. Dana Robertson. After the presentation, the public had the opportunity to ask questions and provide comments to the agency representatives. Letters of support of the proposed projects were read into the record. At the conclusion of the questions and answers session, the public had the opportunity to visit with Corps of Engineers representatives at three different stations: engineering, economics, and environment. Similarly, the Corps of Engineers held a public workshop in the community of Mt. Vernon, near the J.T. Myers L&D, on the evening of February 14, 2000. The purpose of the workshop was for the Corps of Engineers to provide information about the proposed Greenup and Myers lock extension projects. Approximately 11 members of the local community and agency representatives attended the workshop.

No formal presentation or public questions/comments session was scheduled for the workshop. Instead, a continuously playing slide show provided information about the proposed Greenup and Myers locks extensions projects. Also, agency representatives were positioned at engineering, economics, and environmental stations to answer questions about the proposed projects for the public, state and local agency personnel, and the media.

Section 3
ECOSYSTEM RESTORATION AUTHORIZATION STUDY

3.1 FEDERAL REGISTER NOTICE

The Notice of Intent (NOI) was published in the Federal Register on Wednesday October 21, 1998. A similar Public Notice announcing the 3 scoping meetings was mailed to approximately 3,700 agencies, industries and individuals. Comments from letters received regarding the NOI were addressed in the Draft EIS. One comment letter was received from a federal agency.

3.2 INTERAGENCY COORDINATION

Soon after the public scoping meetings, the Corps of Engineers founded an interagency partnership to study the ecological needs and opportunities for the Ohio River corridor. As previously indicated, representatives of the U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency and natural resource agencies of Illinois, Indiana, Kentucky, Ohio, West Virginia and Pennsylvania, were active participants in the study process. During numerous meetings, the interagency partnership and its three working groups identified ecosystem losses and established the goals and opportunities of the proposed Ohio River ecosystem restoration program.

During the early months of the partnership, the Corps requested state natural resource agency officials to identify and prioritize potential site-specific ecosystem restoration projects along the Ohio River corridor. The states provided a list of over 250 projects. Approximately 70 of those projects were further studied to illustrate various ecosystem restoration practices and develop a range of project implementation costs.

3.5 FINAL DECISION DOCUMENT AND ENVIRONMENTAL ASSESSMENT COORDINATION & REVIEW

The Draft Ecosystem Restoration Report – a Decision Document and Environmental Assessment -- was circulated for a 30-day public comment period in August 2000. During that period, various Federal and state agencies, environmental organizations, and the public were afforded the opportunity to review a draft of this report. The Pittsburgh, Huntington and Louisville Districts of the Corps of Engineers issued News Releases regarding the public comment period. Notices of Availability were also mailed to over 3200 recipients.

Following distribution of the Notice of Availability, copies of the report (either printed, or digital copies on CDROM-disk) were also distributed to the general public (on request). The digital versions of the documents were also available to download to personal computers via the Internet from the Louisville District Internet site.

As result of public review, 32 letters and e-mail messages were received. Numerous comments were received from both organizations and individuals. The Finding of No Significant Impact was signed on 12 October 2000.

Section 4
SYSTEM INVESTMENT PLAN

4.1 COMMUNICATION PLAN

As part of the Project Management Plan for the System Investment Study, a comprehensive Communications Plan was developed. That plan laid out the strategic communication objectives for the Ohio River Mainstem System Study. The purpose of the plan was to develop a comprehensive and proactive document that would provide direction and set forth the general guidance and elements of a campaign that would educate and inform internal and external audiences about the Ohio River Mainstem System Study while publicly clarifying and correcting inaccuracies regarding the Study.

Communication with all interested concerns, especially the general public, was considered to be vital to the success of the Ohio River Mainstem Systems Study. Communication activities were unique and multifaceted for this study, making this task extremely difficult to address. Consideration of 19 locks and dams over 981 river miles and involving six states, communication activities for ORMSS did not fit into the models used for past feasibility studies focusing on one or a few facilities.

Although no recommendation for Congressional authorization will be made, the System Investment Plan (SIP) will provide a tool to help determine the timing of future modernization projects and will be used as a basis to schedule and budget future navigation studies. It was and is important that these envisioned modernization projects be subject to adequate scrutiny of key stakeholders and others at appropriate junctures in the study.

The communications strategy for ORMSS was designed to adequately and accurately communicate objectives, process, and results of the study. This included soliciting input and possibly adjusting study processes or assumptions.

The goals of the communication component of the Ohio River Main Stem Study were fourfold: 1) To fully and effectively communicate the ORMSS purpose, thoroughness, and technology applications in order to attain the most complete and effective study results, 2) To build awareness of the significance of Ohio River Navigation, the potential for its significant contribution to the basin's freight transportation capacity (i.e. relieving pressure from overstressed truck and rail modes), and anticipated water transportation problems and solutions for the next sixty years, 3) To involve diverse stakeholders early and often in order to complete an effective study with beneficial and acceptable recommendations, and 4) To communicate the results of the Ohio River SIP.

4.2 SCOPING PROCESS FOR CUMULATIVE EFFECTS ANALYSIS (CEA)

4.3.1 General

An important first step in developing a large-scale environmental impact statement, scoping is mandated by the National Environmental Policy Act whenever major federal actions can significantly affect the quality of the environment. Scoping creates opportunities for the public, agencies and other groups to provide input on potential issues related to a proposed project. By identifying significant environmental issues and potential alternatives, the scoping process directs the course of the study team's efforts in the development of the CEA.

4.3.2 Notice of Intent Federal Register

Scoping for the CEA began with publication of a notice in the Federal Register on June 26, 2001. It also was publicized through a press release announcing the CEA scoping process and inviting comments, a mailing to all addressees on the ORMSS mailing list, and legal ads in major regional newspapers. Interested parties also were encouraged to provide written comments or submit questions to the CEA Project Manager at USACE Louisville District by regular mail or e-mail (celrl-ormss@usace.army.mil) by August 31, 2001. Information about the CEA also was available on the project web site: http://www.lrl.usace.army.mil/ormss/. Additionally, a color brochure was developed and provided to those who attended the public meetings and to others upon request.

4.3.3 Public Meetings

A series of six public scoping meetings (one set in each state along the Ohio River) was held during Summer 2001. Each set consisted of a daytime meeting with governmental agencies and an evening meeting open to the public. Meetings were scheduled as follows:

July 10, 2001 - Banterra Bank, Metropolis, IL
July 12, 2001 - Victory Theater, Evansville, IN
July 31, 2001 - Mid-Ohio Valley Regional Council , Parkersburg, WV
August 1, 2001 - Community College of Beaver Co., Monaca, PA
August 6, 2001 - Kenton Co. Public Library, Covington, KY
August 7, 2001 - Shawnee State University, Portsmouth, OH

Forty-four people attended the six meetings with agency representatives. More than half the participants represented federal and state resource or regulatory agencies. The remaining participants represented various public agencies or business interests.

A total of 141 people signed in at the six public meetings. Nearly 50 percent of the participants were interested citizens. Approximately 25 percent represented business or development interests, with the largest representation from the shipping industry. The remaining participants included fishermen, elected officials, and representatives of environmental groups, the media and government agencies.

Questionnaires also were available at the meetings and online. Nineteen completed questionnaires were submitted. Additionally, written comments received during scoping consisted of several personal and agency letters and e-mail messages. By late summer, 24 written responses had been received.

4.5 INTER-AGENCY WORKING GROUP

At the outset of the study, the environmental team established an Interagency Working Group (IWG) made up of State and Federal natural resource agencies and regulatory personnel. Later in the process non-governmental organizations were also represented in the IWG. The IWG met quarterly during the study to identify issues to be addressed, provide input to the study process, help determine effects, and review results. Although not a part of the formal ITR team, the reviews provided by the IWG were especially valuable to the PDT.

The IWG consists of approximately 40 members representing federal and state agencies with responsibilities for environmental management, as well as several NGOs. Six members were from the U.S. Fish and Wildlife Service, with one serving as the coordinator for the USFWS group; two were from the U.S. Geological Survey; and one was from the U.S. Environmental Protection Agency. Members from NGOs include one person from the Sierra Club, one from the Ohio River Advocacy, and two from The Nature Conservancy. The remaining members are from natural resources or environmental management agencies in the six states bordering the Ohio River. The IWG had two to three meetings annually with the environmental team. These one-day joint meetings included information dissemination and updates related to the status of the CEA study, status reports on specific research projects, and working sessions on integrative topics such as impact matrices for Reasonably Foreseeable Future Actions, or RFFAs,

and indicators and a process for analyses of environmental sustainability (AES). More specifically, the IWG fulfilled the following purposes in the CEA study:

- Aided in identifying key issues and cumulative effects that should be addressed in the CEA study.
- Assisted the CPT in delineating and prioritizing key research needs relative to environmental issues and natural resources. Examples of completed research include fish passage studies at selected locks, determination of winter habitat requirements for selected fish species, and surveys of freshwater mussel populations at various River locations. In addition, the IWG has reviewed the completed research reports.
- Participated in the completion of RFFA matrices for Valued Environmental Components (VECs) and their subcomponents related to aquatic ecological resources, floodplain/riparian ecological resources, and threatened/endangered/protected species.
- Reviewed work plans for addressing cumulative effects on the VECs and their subcomponents; in addition, reviewed the identified methods and procedures relative to "best practice tools" for the specific issues and cumulative effects to be addressed. It should be noted that "best practice tools" infer both scientific validity and cost-effectiveness relative to their application.
- Conducted systematic reviews of draft chapters and appendices for the CEA study report and the SIP/PEIS.
- Provided periodic and continuing scientific information on emerging issues; examples include the incorporation of the environmental sustainability analyses and the need to consider nonstructural measures for navigation traffic management, along with proactive repair and rehabilitation of existing locks and dams, and lock extensions.
- Participated in the planning and implementation of a coordinated and collaborative long-term strategy for environmental monitoring and adaptive environmental management for the aquatic and floodplain/riparian ecological resources within and along the Ohio River mainstem. In fact, the IWG could become part of a long-term decision-making structure and process related to enhancing the environmental sustainability of key resources.

Throughout the study process, environmental considerations were on equal footing with engineering and economics. The extensive communication, outreach, and public/agency inclusion through the Interagency Working Group helped ensure accountability, full disclosure, acceptability, and credibility of environmental considerations prior to recommending or making decisions.

Throughout the ORMSS study, including preparation of the earlier interim feasibility studies, the environmental team maintained regular communication with resource agencies through regularly scheduled meetings with an Interagency Work Group (IWG) held at various locations along the Ohio River. **Table 4-1**, lists the locations and attendees at each of the meetings starting in April 2001, at which time the preparation of the SIP, PEIS, and CEA began in earnest. **Table 4-1** also includes eight meetings (shown

by asterisk) with other professional or multi-agency groups with interests in environmental management.

TABLE 4-1. Environmental Meetings

Date(s) / Meeting/Location	Audience
October 29, 1996/Interagency Team Meeting/Wheeling, WV	USFWS, State Resource Agencies, EPA, NGOs
October 31, 1996/ Interagency Team Meeting/Louisville, KY	USFWS, State Resource Agencies, EPA, NGOs
January 23, 1997/Cincinnati	State Historic Preservation Officers
February 6, 1997/Interagency Team Meeting/Columbus, OH	USFWS, State Resource Agencies, EPA, NGOs
May 21, 1997/In-Progress Review Meeting-/Cincinnati, OH	USFWS, State Resource Agencies, EPA, NGOs, Navigation Industry
August 27, 1997/NAVPAT Model Explanation/Vicksburg, MS	USFWS, State Resource Agencies, EPA, NGOs
November 13, 1997/Interagency Team Meeting/Columbus, OH	USFWS, State Resource Agencies, EPA, NGOs
February 24, 1998, Interagency Team Meeting/Parkersburg, WV	USFWS, State Resource Agencies, EPA, NGOs
April 14-15, 1998, In-Progress Review Meeting/Pittsburgh, PA	USFWS, State Resource Agencies, EPA, NGOs, Navigation Industry
August 7, 1998/Interagency Team Meeting/Cincinnati, OH	USFWS (w/directors), State Resource Agencies, EPA, NGOs
May 27-28, 1998/Interagency Team Meeting/Louisville, KY	USFWS, State Resource Agencies, EPA, NGOs
July 21, 1998/Interagency Team Meeting/Huntington, WV	USFWS, State Resource Agencies, EPA, NGOs
August 12, 1998/Scoping Meeting/Pittsburgh, PA	Pennsylvania Resource Agencies
August 27, 1998/Scoping Meeting/Columbus, OH	Ohio Resource Agencies
October 20-21, 1998/Interagency Team Meeting/Louisville, KY	USFWS, State Resource Agencies, EPA, NGOs
January 26-27, 1999/Interagency Team Meeting/Parkersburg, WV	USFWS, State Resource Agencies, EPA, NGOs
March 30-31, 1999/Interagency Team Meeting/Ashland, KY	USFWS, State Resource Agencies, EPA, NGOs
July 21-22, 1999/Interagency Team Meeting/Evansville, IN	USFWS, State Resource Agencies, EPA, NGOs
October 28-29, 1999/Interagency Team Meeting/Cincinnati	USFWS, State Resource Agencies, EPA, NGOs
January 19, 2000/Ecosystem Restoration Presentation/Frankfort, KY	Ohio River Fish Management Team

January 20-21, 2000/Interagency Team Meeting/Frankfort, KY	USFWS, State Resource Agencies, EPA, NGOs
January 26, 2000/Ecosystem Restoration Presentation/Crittenden, KY	State Resource Agencies
February 9, 2000/Recommendations for Greenup & Myers/Greenup, KY	Environmental Agencies, Navigation Industry & General Public
February 14, 2000/Recommendations for Greenup & Myers/Mt. Vernon, IN	Environmental Agencies, Navigation Industry & General Public
February 15, 2000/Study Update/Somerset, PA	PA Fish and Boat Commission
April 3-4, 2000/Interagency Team Meeting/Frankfort, KY	USFWS, State Resource Agencies, EPA, NGOs
June 13-15, 2000/Ecosystem Restoration Study Update/Marietta, OH	USFWS, State Resource Agencies, EPA, NGOs
July 18-19, 2000/Interagency Team Meeting/Pittsburgh, PA	USFWS, State Resource Agencies, EPA, NGOs
August 4, 2000/Coordination Meeting/Cincinnati, OH	ORSANCO
September 15, 2000/Aquatic Studies Update/Frankfort, KY	USFWS and Ohio River Fish Management Team
October 12, 2000/Recommendations for Ecosystem Restoration Program/Cincinnati, OH	Environmental Agencies, Navigation Industry & General Public
October 24-25, 2000/Interagency Team Meeting/Crittenden, KY	USFWS, State Resource Agencies, EPA, NGOs
November 27-29,.2000/Environmental Monitoring & Assessment/St. Louis, MO	EPA
January 30-31, 2001/Interagency Team Meeting/Columbus, OH	USFWS, State Resource Agencies, EPA, NGOs
February 6-8, 2001/Ecosystem Restoration Meeting/Columbus, OH	USFWS
March 14-16, 2001/Ecosystem Restoration Update/Bettendorf, IA	Mississippi River Conservation Committee
March 26, 2001/Lock Design Workshop (Environmental Considerations) Vicksburg, MS	Corps of Engineers employees
March 31, 2001/Ecosystem Restoration Update/California, PA	Western Pennsylvania Conservancy
April 5, 2001/ Interagency Team Meeting/Frankfort, KY	USFWS, State Resource Agencies, EPA, NGOs
June 5-6, 2001/Ecosystem Restoration Meeting/Louisville, KY	USFWS
July 10, 2001/ORMSS Scoping Meeting/Metropolis, IL	Resource Agencies and General Public
July 11, 2001/Interagency Team Meeting/ Paducah, KY	USFWS, State Resource Agencies, EPA, NGOs

July 12, 2001/ORMSS Scoping Meeting/Evansville, IN	Resource Agencies, Navigation Industry and General Public
July 31, 2001/ORMSS Scoping Meeting/Parkersburg, WV	Resource Agencies, Navigation Industry and General Public
August 1, 2001/ORMSS Scoping Meeting/Beaver, PA	Resource Agencies, Navigation Industry and General Public
August 6, 2001/ORMSS Scoping Meeting/Covington, KY	Resource Agencies, Navigation Industry and General Public
August 7, 2001/ORMSS Scoping Meeting/Portsmouth, OH	Resource Agencies, Navigation Industry and General Public
October 2-3, 2001/Poster Session/Rend Lake, IL	State DNR Directors
October 11, 2001/Poster Session/Louisville, KY	Ohio River Consortium
October 17, 2001/ORMSS Presentation/Covington, KY	Cincinnati Propeller Club
October 25, 2001/Cumulative Effects Assessment Course/Memphis, TN	
November 14-15, 2001, Interagency Team Meeting Cincinnati, OH	USFWS, State Resource Agencies, EPA, NGOs
November 20, 2001, Portsmouth, OH	Shawnee Nature Club, Quarterly Meeting
December 18-19, 2001/ORMSS Presentation/Cincinnati, OH	ORSANCO Advisory Committee
February 1, 2002, Interagency Team Meeting Frankfort, KY	USFWS, State Resource Agencies, EPA, Non-Governmental Offices (NGOs)
February 28-29, 2002, MV MISSISSIPPI	Midwest Natural Resource Leaders Group
March 19-21, 2002, Anstedt, WV	USFWS, Ecosystem Team
June 11, 2002/Interagency Team Meeting/Paducah, KY	USFWS, State Resource Agencies, EPA, NGOs
August 26, 2002/Green River-Ohio River Confluence/Louisville, KY	USFWS, Kentucky DFWR, Kentucky DOT
November 7, 2002/N. Kentucky University	Ohio River Basin Consortium for research and Education
November 13, 2002, Interagency Team Meeting Columbus, OH	USFWS, State Resource Agencies, EPA, NGOs
November 20, 2002/Columbus, OH	TNC
Feb 5, 2003/Cincinnati, OH	Ohio River Fish Management Team
Mar 1, 2003/Cincinnati, OH	Midwest Natural Resources Leaders Group
Apr 23, 2003/Interagency Team Meeting/Cincinnati, OH	USFWS, State Resource Agencies
Jul 9, 2003/Pittsburgh, PA	PA Environmental Council
Sep 9, 2003/Interagency Team Meeting/Marietta, OH	USFWS, State Resource Agencies, EPA, NGOs
Feb. 10-11, 2004/Interagency Team Meeting/Frankfort, KY	USFWS, State Resource Agencies

May 11, 2004/Interagency Team Meeting/Pittsburgh, PA	USFWS, State Resource Agencies
Aug. 18-20, 2004/Ohio River Basin Consortium for Research & Education, St. Louis, MO	USFWS, State Resource Agencies

4.6 WEBSITE

The Corps used two primary means to regularly update the general public with progress and issues throughout development of the SIP. The URL site on the Louisville District Web Page cited above for the Scoping Meeting Comments also contained links to a general fact sheet and compilations of Frequently Asked Questions (FAQs). Two FAQ sheets were maintained, one solely relating to economic modeling and analysis issues, the other for all other types of concerns.

For the time period for which data is available, 14 April 2003 to 21 July 2004, the URL site averaged 9 visits per day on weekdays and 15 visits per weekend. For this time period, the web site had 4,254 visits. Out of these 4,254 visits, 2,137 visits were by unique visitors. This means that the difference between these two numbers, 2117 visitors, or roughly half, were repeat visits. The average number of visits per four-week period is 151, with an average of 76 unique visitors per four-week period.

4.7 FAQs

Sets of Frequently Asked Questions (FAQs) were developed and placed on the ORMSS website. There were three categories of questions; general questions about the study, questions about the Ohio River Ecosystem Restoration authorization study, and questions about the economic analyses conducted for the SIP.

4.8 FACT SHEET

A fact sheet about the ORMSS was developed and placed on the website. The fact sheet contained information about the navigation system on the river and the ORMSS study. The fact sheet was updated as information developed.

4.9 MAIL LIST

A mailing list was developed for the purpose of disseminating information related to the release of the System Investment Plan. This mailing list was develop by starting with mailing lists that were used for the Myers/Greenup study and the Ecosystem Restoration Authorization study. Additional entries were added to the mailing list and obsolete entries deleted as the information on interested parties became available. The

resulting mailing list had over 3,000 entries on it, and was composed of the following major categories:

- City and state officials from the study area, including mayors, governors, and state agencies
- Senators and Members of Congress from the study area
- Non-governmental organizations
- Companies doing business along the river, such as shippers, towing companies, and other users of the navigation facilities on the river
- Organizations of waterways users, such as the Waterways Council
- Other federal agencies
- Libraries in the study area
- Media in the study area
- Other Corps of Engineers districts and divisions
- Private individuals interested in the study

4.10 BROCHURE

A brochure was developed by the Public Affairs office of the Great Lakes and Ohio River Division of the Corps of Engineers. This brochure is entitled, "Ohio River – Future Navigation and Environmental Improvements." The brochure summarizes the ORMSS, focusing on the importance of the navigation system to the region and the System Investment Plan. The brochure also discusses the Ecosystem Restoration Program authorized in the Water Resources Development Act of 2000. This brochure has been distributed at meetings with the general public, environmental interest groups, and state and local officials.

4.11 DISPLAYS

To complement the brochure, a three panel display was developed. This display was a duplicate of the brochure, containing information on the navigation system and the study. This display has been used in a number of venues, including an Ohio River tour of the Motor Vessel Mississippi and a regional convention of the U.S. Fish and Wildlife Service.

4.12 PRESENTATIONS AND TECHNICAL PUBLICATIONS

4.12.1 General Meetings

Besides the Interagency Working Group, other presentations directed to specific technical audiences were accomplished as described in **Table 4-2**. In additional to informing the public and interested parties about the study, any comments generated were considered in technical analyses conducted for this study.

TABLE 4-2. General Meetings

Dates/Meeting/Location	Audience	ORMSS Team Presentation(s)
January 2004/Transportation Research Board/Washington, D.C.	Academic and Business Transportation Officials	ORNIM
July 16-17, 2002/ Economic and Environmental Conference, US Army Corps of Engineers/New Orleans, LA	Water resource professionals from the Corps, academia, government agencies, and various NGOs	Traffic Management
June 2-5, 2005/International Association of Impact Assessment (I.A.I.A.) Conference/Boston MA	Environmental Agencies and NGOs	Study Status, Traffic Forecast Scenarios, Environmental Sustainability, Mussels, Monitoring and Adaptive Management, and Potential Applications of Methodologies

4.12.2 Corps Interaction with Industry

Coordination with industry consisted of several briefings to groups including DINAMO and the Waterways Council, Inc. that focused on progress and preliminary findings. All meetings are listed in Table 4-3.

TABLE 4-3. Meetings and Briefings with Industry Representatives

Dates/Meeting/Location	Audience	ORMSS Presentation(s)
March 2, 2001/Inland Waterways Conference	Inland Waterways Conference Panel	
Nov. 30, 2001/Inland Waterways User Board Meeting/Fort Lauderdale, FL	Inland Waterways User Board	
Apr. 25, 2002/Inland Waterways User Board Meeting/Chattanooga, TN	Inland Waterways User Board[1]	Study Status and Commercial Traffic Forecasting
July 2002/DINAMO[1]/Ligonier, PA	DINAMO (River Transportation)	

	Representatives	
October 31, 2002/DINAMO/Emsworth, PA	DINAMO officials	
March 11-12, 2003/Inland Waterways Conference/Cincinnati, OH	River Transportation Officials	
July 30, 2003/DINAMO/Pittsburgh, PA	DINAMO officials	Study Methodology
September 23, 2003/Houston, TX	National Waterways Conference	
January 13, 2004/Washington, DC	Waterways Council, Inc.	
March 2004/Inland Waterways User Board Meeting/	Inland Waterways User Board	
September 2, 2004/Washington, DC	Waterways Council, Inc., Great Lakes and Ohio River and Mississippi River Divisions of the Corps	
February 23-24, 2005/Tampa, FL	Waterways Council, Inc., Great Lakes and Ohio River and Mississippi River Divisions of the Corps	
March 2005/Inland Waterways User Board Meeting/	Inland Waterways User Board	

[1]Industries represented by IWUB attending meeting included Cargill Marine & Terminal, Alter Barge, Inc. MEMCO Barge Line, Ingram Barge Co., Parker Towing Co., Peabody COALSALES Co., Shaver Transportation, Holcum (US), Inc., CONSOL Energy, Inc., Kirby Corp., and American Barge Line. Also attending was Volunteer Barge & Transport, Inc.

[2]Presentations also made by representatives from HDR, Inc., Balch & Bingham, LCC, J. Simmons Group, Transportation Institute (Houston), Atlantic Intracoastal Waterways Assoc., Transportation Research Board, and House Energy & Water Development Subcommittee.

4.12.3 Motor Vessel Mississippi

During the M/V Mississippi tour of summer 2005, three districts and one division, Huntington, Louisville, Nashville and Great Lakes and Ohio River, hosted events where more than one thousand community members, navigation industry, and families learned about the Ohio River, the importance of navigation and the ORMSS. The annual M/V Mississippi tour is an opportunity for members of the Mississippi River Commission (MRC) to learn about issues associated the Mississippi River and its tributaries. In 2005, the focus of the tour was the Ohio River.

An ORMSS display, handouts and personnel with expertise were made available to the public and special interest representatives aboard the vessel and at scheduled stops down the Ohio River. The vessel was open to touring during scheduled open houses. During these guided informational tours, the ORMSS study was presented and discussed. The study was briefed to USACE HQ representatives and other internal and external

dignitaries – local, state and national. More than 15 briefings on ORMSS, Ecosystem Restoration Program and the current condition of Ohio River navigation were given to congressional delegates, navigation industry leaders, news media and other stakeholders and public interest groups. Environmental agencies were represented in the audiences.

A regional mailing went out to more than 3,000 people to visit the vessel. The Motor Vessel served as an educational river-study "open book" floating down the river. The newly opened National Rivers Institute, Hanover College, Indiana sent their new executive director and a fleet of students to engage leadership and program managers about river biology and navigation. The Louisville Courier Journal ran a regional front-page story and pictorial that circulated to 250,000 homes on riverine ecosystem issues spurred by the Vessel's tour. Spirited dialogue and exchange resulted from the mix of diverse interest groups on how reinvestments could be made to protect and improve the 20 locks on the Ohio River. At the heart of these discussions, was the importance and future impact of the ORMSS and accompanying System Investment Plan.

Participants included the ORMSS project manager, Division and District Public Affairs Officers, and other ORMSS team members, civil project managers, lock personnel and those with navigation expertise.

Table 4-4 contains a listing of activities where ORMSS was presented, discussed or highlighted.

TABLE 4-4. Meetings and Briefings during the M/V Mississippi Tour

Event	Location	Comment
Ribfest	David W. Harris Park, Huntington, West Virginia	Public tours, Open House, presentations
MRC Commissioner's Meeting	On board	
MRC, LRD, Pittsburgh and Huntington, Louisville District Briefings	On board	
Greenup Lock and Dam briefing/tour	On site	
Meldahl Lock and Dam Briefing/tour	On site	
Public Open House and tours	Cincinnati Riverfront	
ORMSS, Ecosystem Restoration briefs, Markland Major Rehabilitation brief	Markland L&D - On site, on board	Stakeholders, Congressional staff, public interest group representation, Waterways Council
History of navigation on the Ohio River	On board	

briefing		
Media visits, public tours on site, open house	Louisville Riverfront	
McAlpine Lock Replacement Project tour	On site	
Louisville Repair Station and Falls of the Ohio tour	On site	
Cannelton Locks and Dam tour	On site	
Southwinds Indiana Port tour and navigation updates	Mt. Vernon, Indiana	
Olmsted Lock and Dam construction project tour	On site	
John T. Myers Lock and Dam tour	On site	
Smithland Lock and Dam	On site	
Cumberland River	On board	
Barkley Lock and Dam	On site	
Tennessee River	On site	
Kentucky Lock and Dam	On site	
Paducah Riverfront Public open house, tours	Paducah, Kentucky	

4.14 REPORT RELEASE INFORMATION

As the report was readied for release to the public, a roll-out plan was developed. The prime objective of this roll-out plan was to develop strategies to effectively inform target audiences of release of draft report, particularly to notify target audiences of 60-day comment period, tell target audiences where they can access report, and explain how they can submit written comments. Toward that end, a goal developed in the roll-out plan was to package and present preliminary study findings in a concise and comprehensive format. Additionally, the roll-out plan was developed to help all members of the study team focus on key messages related to the findings contained in the report, particularly:

- To highlight the innovative nature of the of study methodology.
- To emphasize the appropriateness of the study methodology for the Ohio River System.

- To relay the information that the report does not seek any additional authorization
- To explain study methodology, forecasting and economics
- To emphasize the use of outside agency/university review during the study development
- To explain how the cumulative effects analysis was conducted

To announce the availability of the System Investment Plan, a direct mailing will be made to all of the members of the mailing list. A post card will be used for the majority of the mailing list, primarily those individuals and agencies not required to receive a copy of the report. The post cards will be mailed one week prior to planned release of draft report. This post card will contain the following information:

- Availability of the draft SIP for review
- Web site address of report
- How to view a copy of report
- How to obtain a copy of report
- Dates and locations of public meetings
- Dates of the public review period

As throughout the entire study period, the ORMSS website will continue to function as a primary communications tool. The mailing will direct interested parties to the website. Both the mailing and the website will explain how to obtain paper or electronic copies of the report. The website will also continue to contain Frequently Asked Questions, updated at the time to the report release to summarize the report findings, answer questions about how to obtain a copy of the report, and inform interested parties about public involvement activities. Additionally, the report itself will be placed on the website, so that interested parties may be able to view it. An e-mail link will be provided for those who wish to submit comments.

Public meetings will be held at six sites, in six different states. The locations are listed below:

- Metropolis, Illinois
- Evansville, Indiana
- Covington, Kentucky
- Huntington, West Virginia
- Marietta, Ohio
- Beaver, Pennsylvania

Visual aids will be developed for the public meetings: maps, handouts, PowerPoint presentations, etc. Press releases will announce the release of the draft report and provide information on the report's results. These press releases will also announce public meetings and provide information about viewing the report and obtaining a copy.

Media training was conducted for the Project Delivery Team, in order that those most familiar with the report, its methodology, and the results be trained to help disseminate information to the media and public effectively.

4.15 DATABASE MANAGEMENT

In the course of preparing this System Investment Plan, a considerable quantity of data and analyses has been developed, particularly for the Cumulative Effects Analysis. Many of the agencies that participated in the Interagency Working group have expressed interest in the availability of this information. During future phases of this study, the possibility of making this data available to interested agencies will be investigated.