

SAVANNAH HARBOR EXPANSION PROJECT CHATMAN  
COUNTY, GEORGIA AND JASPER COUNTY, SOUTH  
CAROLINA: FINAL GENERAL RE-EVALUATION RE-  
PORT AND ENVIRONMENTAL IMPACT STATEMENT  
JANUARY 2012

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**GENERAL RE-EVALUATION REPORT**  
SAVANNAH HARBOR EXPANSION PROJECT  
Chatham County, Georgia and Jasper County, South Carolina

**January 2012**  
(Revised July 2012)

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Appendix C  
to  
Appendix C  
Attachment 3  
Part 5

Volume 2



US Army Corps of  
Engineers  
Savannah District  
South Atlantic Division





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# GENERAL RE-EVALUATION REPORT

## APPENDIX C: ENGINEERING

### SAVANNAH HARBOR EXPANSION PROJECT

Chatham County, Georgia and Jasper County, South Carolina

January 2012

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**US Army Corps  
of Engineers**  
Savannah District  
South Atlantic Division

This report is **Appendix C**  
to the **General Re-Evaluation Report** for  
the **Savannah Harbor Expansion Project**  
located in Chatham County, Georgia and  
Jasper County, South Carolina.

## Acronyms and Abbreviations

|                     |                                                         |
|---------------------|---------------------------------------------------------|
| <b>AFB</b>          | Alternative Formulation Briefing                        |
| <b>AIWW</b>         | Atlantic Intracoastal Waterway                          |
| <b>ANN</b>          | Artificial Neural Networks                              |
| <b>ASA</b>          | Assistant Secretary of the Army                         |
| <b>ATM</b>          | Applied Technology and Management, Inc.                 |
| <b>ATR</b>          | Agency Technical Review                                 |
| <b>BL</b>           | Base/Bilge Line                                         |
| <b>BR</b>           | Back River                                              |
| <b>CADET</b>        | Channel Analysis & Design Evaluation Tool               |
| <b>CB</b>           | Container Berth                                         |
| <b>CDF</b>          | Confined Disposal Facilities                            |
| <b>CEDEP</b>        | Corps of Engineers Dredge Estimating Program            |
| <b>CH</b>           | High liquid limit clay                                  |
| <b>CHL</b>          | Coastal and Hydraulics Laboratory                       |
| <b>CL</b>           | Low liquid limit clay                                   |
| <b>CWCCIS</b>       | Civil Works Construction Cost Index System              |
| <b>CWE</b>          | Current Working Estimate                                |
| <b>CZM</b>          | Coastal Zone Management                                 |
| <b>DMCA</b>         | Dredged Material Containment Areas                      |
| <b>DMMP</b>         | Dredged Management and Material Plan                    |
| <b>DO</b>           | Dissolved Oxygen                                        |
| <b>DOT</b>          | Department of Transportation                            |
| <b>DOTS</b>         | Dredging Operations Technical Support                   |
| <b>DQC</b>          | District Quality Control                                |
| <b>EFDC</b>         | Environmental Fluid Dynamics Computer Code              |
| <b>EIS</b>          | Environmental Impact Statement                          |
| <b>EN</b>           | Engineering                                             |
| <b>EPA</b>          | Environmental Protection Agency                         |
| <b>ERDC</b>         | Engineering Research and Development Center             |
| <b>EWT</b>          | Effective Work Time                                     |
| <b>FEMA</b>         | Federal Emergency Management Agency                     |
| <b>FIS</b>          | Flood Insurance Study                                   |
| <b>GAEPD</b>        | Georgia Environmental Protection Division               |
| <b>GIS</b>          | Geographic Information System                           |
| <b>GP</b>           | Poorly graded gravels                                   |
| <b>GPA</b>          | Georgia Ports Authority                                 |
| <b>GRR</b>          | General Reevaluation Report                             |
| <b>HH&amp;C CoP</b> | Hydrology, Hydraulics and Coastal Community of Practice |
| <b>HTRW</b>         | Hazardous, Toxic, and Radioactive Waste                 |
| <b>IEPR</b>         | Independent External Peer Review                        |

|                   |                                                               |
|-------------------|---------------------------------------------------------------|
| <b>IP</b>         | International Paper                                           |
| <b>IWR</b>        | Institute for Water Resources                                 |
| <b>JOI</b>        | Jones/Oysterbed Island                                        |
| <b>KITB</b>       | King's Island Turning Basin                                   |
| <b>LNG</b>        | Liquefied Natural Gas                                         |
| <b>LTMS</b>       | Long Term Management Strategy                                 |
| <b>M2M</b>        | Model-to-Marsh                                                |
| <b>MCACES</b>     | Microcomputer Aided Cost Estimating System                    |
| <b>MGD</b>        | Million Gallons per Day                                       |
| <b>MH</b>         | High liquid limit silt                                        |
| <b>MHW</b>        | Mean High Water                                               |
| <b>ML</b>         | Low liquid limit silt                                         |
| <b>MLLW</b>       | Mean Lower Low Water                                          |
| <b>MLW</b>        | Mean Low Water                                                |
| <b>MR</b>         | Middle River                                                  |
| <b>MSM</b>        | Marsh-succession Model                                        |
| <b>MSL</b>        | Mean Sea Level                                                |
| <b>MTL</b>        | Mean Tide Level                                               |
| <b>MTRG</b>       | Modeling Technical Review Group                               |
| <b>NAVD</b>       | North American Vertical Datum                                 |
| <b>NED</b>        | National Economic Development                                 |
| <b>NGVD</b>       | National Geodetic Vertical Datum                              |
| <b>NMFS</b>       | National Marine Fisheries                                     |
| <b>NOAA</b>       | National Oceanic and Atmospheric Administration               |
| <b>NSBL&amp;D</b> | New Savannah Bluff Lock and Dam                               |
| <b>O&amp;M</b>    | Operations and Maintenance                                    |
| <b>ODMDS</b>      | Ocean Dredged Material Disposal Site                          |
| <b>OH</b>         | Organic silts                                                 |
| <b>OSHA</b>       | Occupational Safety and Health Administration                 |
| <b>OSI</b>        | Ocean Surveys, Incorporated                                   |
| <b>PAH</b>        | Polycyclic Aromatic Hydrocarbons                              |
| <b>PCB</b>        | Polychlorinated Biphenyls                                     |
| <b>PD</b>         | Planning Division                                             |
| <b>PDT</b>        | Project Design Team                                           |
| <b>PED</b>        | Planning, Engineering, and Design                             |
| <b>PIANC</b>      | World Association for Waterborne Transport Infrastructure     |
| <b>RMSE</b>       | Root Mean Square Error                                        |
| <b>S&amp;A</b>    | Supervision and Administration                                |
| <b>SAD</b>        | South Atlantic Division                                       |
| <b>SAS</b>        | Savannah District                                             |
| <b>SC</b>         | Clayey sands                                                  |
| <b>SCDHEC</b>     | South Carolina Department of Health and Environmental Control |

|              |                                           |
|--------------|-------------------------------------------|
| <b>SEG</b>   | Stakeholders Evaluation Group             |
| <b>SET</b>   | Scientific and Engineering Technology     |
| <b>SHEP</b>  | Savannah Harbor Expansion Project         |
| <b>SM</b>    | Silty sands                               |
| <b>SNG</b>   | Southern Natural Gas                      |
| <b>SNS</b>   | Shortnose sturgeon                        |
| <b>SOD</b>   | Sediment Oxygen Demand                    |
| <b>SP</b>    | Poorly graded sands                       |
| <b>SPT</b>   | Standard Penetration Test                 |
| <b>SRBA</b>  | Savannah River Below Augusta              |
| <b>STS</b>   | Ship Tow Simulator                        |
| <b>TMDL</b>  | Total Maximum Daily Load                  |
| <b>TPCS</b>  | Total Project Cost Summary                |
| <b>TS</b>    | Technical Services                        |
| <b>USACE</b> | United States Army Corps of Engineers     |
| <b>USCG</b>  | United States Coast Guard                 |
| <b>USFWS</b> | United States Fish and Wildlife Service   |
| <b>USGS</b>  | United States Geological Survey           |
| <b>VE</b>    | Value Engineering                         |
| <b>WASP</b>  | Water quality Analysis Simulation Package |

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## Attachments

### **ATTACHMENT 1**

Channel Design Drawings and Typical Sections

### **ATTACHMENT 2**

MCACES-MII Cost Estimate and Total Project Cost Summary (TCPS) Agency Technical Review (ATR) Certification

### **ATTACHMENT 3**

Engineering Investigations Supplemental Materials (CD)

### **ATTACHMENT 4**

Project Cost and Schedule Risk Analysis Report



## 1.0 INTRODUCTION

The purpose of this appendix is to present the results of engineering studies, investigations, and analyses that have been performed in developing the recommended project improvements for the Savannah Harbor Expansion Project (SHEP).

The current Savannah Harbor Expansion project authorization included in Section 101 of the Water Resources Development Act of 1999 authorized a deep draft navigation project up to a depth of 48 ft below MLLW subject to further evaluation by the agencies and concurrence by the Secretaries of the Army, Commerce, and Interior and the Administrator of the Environmental Protection Agency (EPA). Given the unique authorization of this project, any final recommendation of a preferred plan must meet the requirements of the legislation. Therefore, the engineering evaluations were performed for project depth alternatives ranging from 44 to 48 ft below MLLW, a maximum of 6 ft below the currently authorized navigation channel at 42 ft below MLLW. **Table 1.0-1** shows the plan descriptions for each depth alternative.

Within this range of feasible depths, an NED plan of 47 ft below MLLW was selected, which complies with Army policy. Prior to release of the Draft GRR and EIS for agency and public comment, the State of Georgia asked the Corps to consider the 48-foot depth alternative as the Locally Preferred Plan. As a result of comments received and subsequent discussions with the sponsor, the Corps declined to select the 48-foot alternative for implementation.

Conclusions presented in this appendix are based on previous studies, studies performed specifically for this project, field investigations, laboratory analyses, numerical modeling, available data and engineering experience in the project area over the full range of project alternatives (44 ft to 48 ft below MLLW). Technical studies were performed by the USACE Savannah, Charleston, Mobile and Wilmington Districts, the USACE Engineering Research and Development Center (ERDC) Waterways Experiment Station, other government agencies, such as the US Geological Survey and the US Fish and Wildlife Service, and contract technical consultants. Input from project users and the Stakeholders Evaluation Group (SEG) was also considered in evaluating alternatives.

The major design elements evaluated in this phase of the project are the refinement of the proposed channel alignment; impacts to the groundwater aquifer, water quality, marine habitat, and barrier islands; placement of the dredged material and disposal area capacity, and the effect deepening may have on water surface elevations, current velocity, and sedimentation in the navigation channel. USACE guidance used in preparation of this appendix includes:

ER 1110-2-1150, *Engineering and Design for Civil Works Projects*, 31 August 1999  
 ER 1110-2-1403, *Studies by Coastal, Hydraulic, and Hydrologic Facilities and Others*, 1 January 1998  
 EM 1110-2-1613, *Hydraulic Design of Deep-Draft Navigation Projects*, 31 May 2006  
 ER 1110-2-1302, *Civil Works Cost Engineering*, 15 September 2008  
 EC 1165-2-212, *Sea-Level Change Considerations for Civil Works Programs*, 1 October 2011  
 EM 1110-2-1100, *Coastal Engineering Manual*, 2002  
 EM 1110-2-2504, *Design of Sheet Pile Walls*, 31 March 1994  
 EM 1110-2-1601, *Hydraulic Design of Flood Control Channels*, 30 June 1994  
 EM 110-2-1607, *Tidal Hydraulics*, 15 March 1991

The results from the vast spectrum of engineering investigations completed for this project are outlined and summarized within this document. The related reports, drawings, and correspondence that went into the development of this document are provided in full in the Engineering Investigations Supplemental Materials in electronic format (Attachment 3). See Section 1.1 for a complete list of these reference documents.

**Table 1.0-1: Project Alternatives and Plan Description**

| <b>Project Alternative</b> | <b>Plan Description</b>                                                                                                                                                                                                                                                                                                                                                                                                 |
|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 44 Foot Depth              | Channel deepening to a controlling depth of 44 feet below MLLW.<br>Construction of:<br>2 meeting areas; flow-altering mitigation Plan 6B; Dissolved Oxygen injection system; striped bass hatchery funding; New Savannah Bluff Lock and Dam fish passage structure; and Back River boat access alternative;<br>CSS Georgia archaeological data recovery. Mitigation monitoring.                                         |
| 45 Foot Depth              | Channel deepening to a controlling depth of 45 feet below MLLW.<br>Construction of:<br>2 meeting areas; flow-altering mitigation Plan 6A; Dissolved Oxygen injection system; striped bass hatchery funding; New Savannah Bluff Lock and Dam fish passage structure, Back River boat access alternative;<br>CSS Georgia archaeological data recovery.<br>Mitigation land acquisition 1,643 acres. Mitigation monitoring. |
| 46 Foot Depth              | Channel deepening to a controlling depth of 46 feet below MLLW.<br>Construction of:<br>2 meeting areas; flow-altering mitigation Plan 6A; Dissolved Oxygen injection system; striped bass hatchery funding; New Savannah Bluff Lock and Dam fish passage structure, Back River boat access alternative;<br>CSS Georgia archaeological data recovery.<br>Mitigation land acquisition 2,188 acres. Mitigation monitoring. |
| 47 Foot Depth              | Channel deepening to a controlling depth of 47 feet below MLLW.<br>Construction of:<br>2 meeting areas; flow-altering mitigation Plan 6A; Dissolved Oxygen injection system; striped bass hatchery funding; New Savannah Bluff Lock and Dam fish passage structure, Back River boat access alternative;<br>CSS Georgia archaeological data recovery.<br>Mitigation land acquisition 2,245 acres. Mitigation monitoring. |
| 48 Foot Depth              | Channel deepening to a controlling depth of 48 feet below MLLW.<br>Construction of:<br>2 meeting areas; flow-altering mitigation Plan 6A; Dissolved Oxygen injection system; striped bass hatchery funding; New Savannah Bluff Lock and Dam fish passage structure, Back River boat access alternative;<br>CSS Georgia archaeological data recovery.<br>Mitigation land acquisition 2,683 acres. Mitigation monitoring. |

## 1.1 ENGINEERING INVESTIGATIONS SUPPLEMENTAL MATERIALS

|    |                                  |                                                                                                                                                                       |                |
|----|----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|
| 1  | BTG Inc.                         | Revised 35% Design Construction Estimate New Savannah Bluff Dam Fish Passage Facility Richmond County, Georgia                                                        | December 2002  |
| 2  | Concord Project Consulting, Inc. | Value Engineering Study Summary Report Savannah Harbor Expansion Project                                                                                              | June 2008      |
| 3  | FRAMATOME ANP DE&S, Inc.         | New Savannah Bluff Lock and Dam Project Savannah River Georgia and South Carolina Fish Passage Facility Engineering Report                                            | December 2002  |
| 4  | Tetra Tech, Inc.                 | Oxygen Injection Design Report Savannah Harbor Expansion Project                                                                                                      | October 2010   |
| 5  | Tetra Tech, Inc.                 | Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project                                                                    | January 2006   |
| 6  | Tetra Tech, Inc.                 | Habitat Impacts of the Savannah Harbor Expansion Project                                                                                                              | October 2006   |
| 7  | Tetra Tech, Inc.                 | Savannah Harbor Expansion Project – Chloride Data Analysis and Model Development                                                                                      | November 2006  |
| 8  | Tetra Tech, Inc.                 | Water Quality Impacts of the Savannah Harbor Expansion Project                                                                                                        | February 2007  |
| 9  | US Geological Survey             | Simulations of Water Levels and Salinity in the Rivers and Tidal Marshes in the Vicinity of the Savannah National Wildlife Refuge, Coastal South Carolina and Georgia | June 2006      |
| 10 | USACE ERDC/CHL                   | DOTS Program Savannah District Request for Technical Assistance Dredge Vertical Construction Accuracy                                                                 | March 2006     |
| 11 | USACE ERDC/CHL                   | Memorandum Subject: Savannah Harbor Entrance Channel Simulations 2010 Report                                                                                          | March 2010     |
| 12 | USACE ERDC/CHL                   | Memorandum Subject: Savannah Harbor Simulations Study 2009                                                                                                            | March 2009     |
| 13 | USACE ERDC/CHL Dennis Webb       | Navigation Study for Savannah Harbor Channel Improvements                                                                                                             | September 2004 |

|    |                                                                                                        |                                                                                                                           |                |
|----|--------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|----------------|
| 14 | USACE ERDC/CHL<br>Jane McKee Smith,<br>Donald K. Stauble,<br>Brian P. Williams, and<br>Raymond Chapman | Impacts of Savannah Harbor Expansion<br>Project                                                                           | October 2006   |
| 15 | USACE ERDC/CHL<br>Joseph Z. Gailani, S.<br>Jarrell Smith, Layla<br>Raad, and Bruce<br>Ebersole         | Savannah Harbor Entrance Channel:<br>Nearshore Placement of Dredged Material<br>Study                                     | July 2003      |
| 16 | USACE ERDC/CHL<br>Michael J. Briggs and<br>William G. Henderson                                        | Vertical Ship Motion Study for Savannah,<br>GA Entrance Channel                                                           | June 2011      |
| 17 | USACE ERDC/CHL<br>Stephen T. Maynord                                                                   | Ship Forces on the Shoreline of the<br>Savannah Harbor Project                                                            | August 2006    |
| 18 | USACE Savannah<br>District SAS                                                                         | Correspondence between USACE &<br>Federal/State Agencies Regarding<br>Hydrodynamic & Water Quality Model<br>Acceptability | 2005/2006      |
| 19 | USACE Savannah<br>District SAS-EN                                                                      | Channel Extension Boring Locations                                                                                        | April 2010     |
| 20 | USACE Savannah<br>District SAS-EN                                                                      | Chloride Impact Evaluation Impacts of<br>Harbor Deepening Only                                                            | February 2007  |
| 21 | USACE Savannah<br>District SAS-EN                                                                      | Hurricane Surge Modeling                                                                                                  | September 2005 |
| 22 | USACE Savannah<br>District SAS-EN                                                                      | Memorandum Subject: Material Fines for<br>Savannah Harbor Sediments, Station<br>+103+000 thru -85+000 and KITB            | August 2003    |
| 23 | USACE Savannah<br>District SAS-EN                                                                      | Review and Costs for Supplemental Water<br>Supply City of Savannah Intake at<br>Abercorn Creek                            | September 2009 |
| 24 | USACE Savannah<br>District SAS-EN                                                                      | Savannah Harbor Expansion Bank<br>Erosion Study                                                                           | July 2010      |
| 25 | USACE Savannah<br>District SAS-EN                                                                      | Savannah Harbor Expansion Bank<br>Erosion Study Update                                                                    | June 2011      |
| 26 | USACE Savannah<br>District SAS-EN                                                                      | Savannah Harbor Expansion Bank<br>Stability Report Analysis and<br>Reevaluation Summary                                   | July 2010      |
| 27 | USACE Savannah<br>District SAS-EN                                                                      | Savannah Harbor Expansion General<br>Reevaluation Report Dredged Material<br>Physical Analysis Report                     | 2002           |

|    |                                |                                                                                                                                 |                |
|----|--------------------------------|---------------------------------------------------------------------------------------------------------------------------------|----------------|
| 28 | USACE Savannah District SAS-EN | Savannah Harbor Expansion Project Evaluation of Chloride Impacts with Proposed Mitigation Plan                                  | December 2007  |
| 29 | USACE Savannah District SAS-EN | Savannah Harbor Expansion Project Evaluation of Fishery Habitat Impacts with Proposed Mitigation Plan                           | January 2010   |
| 30 | USACE Savannah District SAS-EN | Savannah Harbor Expansion Project Evaluation of Hurricane Surge Impacts with Proposed Mitigation Plan                           | December 2007  |
| 31 | USACE Savannah District SAS-EN | Savannah Harbor Expansion Project Evaluation of Marsh/Wetland Impacts with Proposed Mitigation Plan                             | November 2007  |
| 32 | USACE Savannah District SAS-EN | Savannah Harbor Expansion Project Evaluation of Water Quality Impacts with Proposed Mitigation Plan                             | September 2009 |
| 33 | USACE Savannah District SAS-EN | Savannah Harbor Expansion Project Mitigation Evaluation for Marsh/Wetland Impacts                                               | November 2007  |
| 34 | USACE Savannah District SAS-EN | Savannah Harbor Expansion Project Sensitivity Analysis of Proposed Navigation Meeting Areas                                     | September 2009 |
| 35 | USACE Savannah District SAS-EN | Savannah Harbor Expansion Project Sensitivity Analysis of Proposed Sill on Middle River                                         | September 2009 |
| 36 | USACE Savannah District SAS-EN | Supplemental Studies to Determine Potential Groundwater Impacts to the Upper Floridan Aquifer Savannah Harbor Expansion Project | June 2007      |
| 37 | USACE Savannah District SAS-EN | Wetland/Marsh Impact Evaluation                                                                                                 | February 2007  |
| 38 | USACE Savannah District SAS-PD | Savannah Harbor Data Analysis & Modeling Expectations of Federal Agencies                                                       | November 2001  |
| 39 | USACE Savannah District SAS-PD | Savannah Harbor Expansion Project Dredged Material Management Plan                                                              | January 2012   |
| 40 | USACE Savannah District SAS-PD | Savannah Harbor Expansion Project Impacts to O&M                                                                                | January 2012   |
| 41 | USACE Savannah District SAS-PD | Savannah Harbor Long Term Management Strategy                                                                                   | August 1996    |

|    |                                                                                                             |                                                                                                                              |               |
|----|-------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|---------------|
| 42 | USACE Savannah District SAS-PD                                                                              | Sediment Quality Evaluation                                                                                                  | January 2012  |
| 43 | USACE Savannah District SAS-PM                                                                              | Correspondence Between USACE and Utilities Regarding Pipeline Crossings                                                      | May 2008      |
| 44 | USACE Wilmington District SAW-TS                                                                            | Sedimentation Analysis                                                                                                       | July 2009     |
| 45 | USACE Mobile District SAM                                                                                   | Savannah Harbor Deepening Project<br>ATM Marsh Succession Model<br>Marsh/Wetland Impact Evaluation                           | May 2007      |
| 46 | USACE Mobile District SAM                                                                                   | Savannah Harbor Deepening Project<br>USGS/USFWS Marsh Succession Model<br>Marsh/Wetland Impact Evaluation                    | June 2007     |
| 47 | MACTEC                                                                                                      | Identification and Screening Level<br>Evaluation of Measures to Improve<br>Dissolved Oxygen in the Savannah River<br>Estuary | June 2005     |
| 48 | MACTEC                                                                                                      | Savannah Harbor Reoxygenation<br>Demonstration Project                                                                       | January 2008  |
| 49 | MACTEC                                                                                                      | Savannah Harbor Reoxygenation<br>Demonstration Project<br>Supplemental Data Evaluation Report                                | August 2009   |
| 50 | Tetra Tech Inc.                                                                                             | Modeling of GPA's Oxygen Injection<br>Demonstration Project                                                                  | July 2009     |
| 51 | USACE Savannah District SAS-EN                                                                              | Savannah Harbor Expansion Project<br>Evaluation of Adult SNS (Summer)<br>Habitat Impacts with Proposed Mitigation<br>Plan    | March 2011    |
| 52 | USACE Savannah District SAS-EN                                                                              | Savannah Harbor Expansion Project<br>Evaluation of Adult SNS (Winter) Habitat<br>Impacts with Proposed Mitigation Plan       | March 2011    |
| 53 | USACE Savannah District SAS-EN                                                                              | Savannah Harbor Expansion Project<br>Evaluation of Juvenile SNS (Winter)<br>Habitat Impacts with Proposed Mitigation         | March 2011    |
| 54 | Tetra Tech, Inc. &<br>Advanced Data<br>Mining Services, LLC                                                 | Chloride Modeling Savannah Harbor<br>Expansion Project                                                                       | December 2010 |
| 55 | USACE ERDC/CHL<br>Jane McKee Smith,<br>Donald K. Stauble,<br>Brian P. Williams, and<br>Michael J. Wutkowski | Impact of Savannah Harbor Deep Draft<br>Navigation Project on Tybee Island Shelf<br>and Shoreline                            | April 2008    |

|    |                                                 |                                                                                                                |               |
|----|-------------------------------------------------|----------------------------------------------------------------------------------------------------------------|---------------|
| 56 | Arthur Freedman Associates, Inc.                | Assessment of Chloride Impact from Savannah Harbor Deepening                                                   | April 2011    |
| 57 | USACE ERDC/CHL                                  | Reanalysis of Ship Forces at the Shoreline in Savannah Harbor                                                  | July 2011     |
| 58 | US Geological Survey                            | Simulation of Specific Conductance and Chloride Concentration in Abercorn Creek, Georgia                       | June 2011     |
| 59 | USACE Savannah District SAS-PD                  | Savannah Harbor Expansion Project Channel Extension Evaluation                                                 | July 2011     |
| 60 | USACE Savannah District SAS-EN                  | Savannah Harbor Expansion Project Evaluation of Marsh/Wetland Impacts with Proposed Mitigation Plan (Addendum) | July 2011     |
| 61 | Tetra Tech, Inc. & Eco Oxygen Technologies, LLC | Analysis of Oxygen Injection in the Back River                                                                 | July 2011     |
| 62 | Tetra Tech, Inc.                                | Model Comparison Report                                                                                        | July 2011     |
| 63 | Camp Dresser & McKee                            | City of Savannah Seawater Effects Study                                                                        | December 2011 |
| 64 | Camp Dresser & McKee                            | Raw Water Impoundment Geotechnical Evaluation Memorandum                                                       | December 2011 |

## 1.2 CHANNEL STATIONING

Currently, the federally authorized navigation channel extends from 60,000 feet (11.4 miles) offshore, across the ocean bar, to 112,500 feet (21.3 miles) upstream on the Savannah River. Stationing, along the navigation channel, is designated every 1,000 feet. Station 0 is located at the mouth of the river at Fort Pulaski. The standard notation for the stationing is in thousands of feet designated as +000. For example, Station 20+000 is 20,000 feet upstream of the mouth of the entrance channel. To determine the river mile, divide by 5,280 feet/mile i.e., Station 20+000 is located at river mile 3.8. Stations on the bar or entrance channel are designated by a negative number. For example, Station -40+000 is located 40,000 feet (7.6 miles) offshore from the mouth of the river.

Stationing for the SHEP 47 ft project extends from -97+680 (mouth of the entrance channel offshore) to 103+000 (upstream of GPA's Port Wentworth Terminal on the Savannah River). The Federally authorized navigation project extends up to Station 112+500. However, the depths proposed for SHEP



only extend up to Station 103+000. The total length of the SHEP navigation channel is 38.0 miles. This length is an increase of 7.1 miles from the currently authorized navigation channel due to the extension of the offshore entrance channel.

### 1.3 DATUMS

Several datums are referenced throughout the numerous reports and studies completed for the SHEP for various reasons (See **Table 1.3-1**). The hydrodynamic modeling references elevations in meters to the NGVD29 datum, while the bathymetry is surveyed in feet referencing mean lower low water (MLLW) based on the 1983-2001 tidal epoch.

**Table 1.3-1: Referenced Datums Used in Engineering Studies**

| Engineering Investigations Supplemental Materials |                                                                                   | Datum Used                           |
|---------------------------------------------------|-----------------------------------------------------------------------------------|--------------------------------------|
| 2                                                 | Value Engineering Study Summary Report<br>Savannah Harbor Expansion Project       | MLW, MLLW                            |
| 3                                                 | New Savannah Bluff Lock & Dam Fish Passage<br>Facility Engineering Report         | NGVD                                 |
| 4                                                 | Oxygen Injection Design Report                                                    | NGVD, MLLW                           |
| 5                                                 | Development of the Hydrodynamic and Water<br>Quality Models                       | meters NGVD                          |
| 9                                                 | Simulations of the Water Levels and Salinity in the<br>Rivers and Tidal Marshes   | MLLW, NAVD                           |
| 14                                                | Impacts of the Savannah Harbor Expansion Projects                                 | MLW, MHW, MLLW,<br>NAVD, meters NGVD |
| 15                                                | Savannah Harbor Entrance Channel Nearshore<br>Placement of Dredged Material Study | MTL, MLW                             |
| 16                                                | Vertical Ship Motion Study for Savannah, GA<br>Entrance Channel                   | MLLW                                 |
| 17                                                | Ship Forces on the Shoreline of the Savannah<br>Harbor Project                    | MLLW                                 |
| 19                                                | Channel Extension Boring Locations                                                | MLLW                                 |
| 21                                                | Hurricane Surge Modeling                                                          | meters NGVD                          |
| 24                                                | Savannah Harbor Expansion Bank Erosion Study                                      | MLLW                                 |
| 25                                                | Savannah Harbor Expansion Bank Erosion Study<br>Update                            | MLLW                                 |
| 26                                                | Savannah Harbor Expansion Bank Stability Report                                   | MLW                                  |



**Table 1.3-1: Referenced Datums Used in Engineering Studies (Continued)**

| Engineering Investigations Supplemental Materials |                                                                     | Datum Used                  |
|---------------------------------------------------|---------------------------------------------------------------------|-----------------------------|
| 27                                                | Dredged Material Physical Analysis Report                           | MLW                         |
| 28                                                | Evaluation of Chloride Impacts and Proposed Mitigation Plan         | NGVD                        |
| 29                                                | Evaluation of Fishery Habitat Impacts with Proposed Mitigation Plan | NGVD, MLLW                  |
| 30                                                | Evaluation of Hurricane Surge Impacts with Proposed Mitigation Plan | meters NGVD                 |
| 31                                                | Evaluation of Marsh Wetland Impacts with Proposed Mitigation Plan   | meters NGVD                 |
| 32                                                | Evaluation of Water Quality Impacts with Proposed Mitigation Plan   | meters NGVD                 |
| 33                                                | Mitigation Evaluation for Marsh Wetland Impacts                     | meters NGVD                 |
| 34                                                | Sensitivity Analysis of Proposed Navigation Meeting Areas           | meters NGVD                 |
| 35                                                | Sensitivity Analysis of Proposed Sill on Middle River               | NGVD, MLLW                  |
| 36                                                | Potential Ground-Water Impacts to the Upper Floridian Aquifer       | MLW, NAD83, MLLW, MSL, NGVD |
| 39                                                | Dredged Material Management Plan                                    | MHW, MLW                    |
| 40                                                | Savannah Harbor Expansion Project Impacts to O&M                    | MLLW                        |
| 41                                                | Savannah Harbor Long Term Management Strategy                       | MLW, MHW                    |
| 42                                                | Sediment Quality Evaluation                                         | MLW                         |
| 43                                                | Correspondence Regarding Pipeline Crossings                         | MLLW                        |
| 44                                                | Sedimentation Analysis                                              | MLW, meters NGVD, MLLW      |
| 63                                                | City of Savannah Seawater Effects Study                             | NAVD                        |
| 64                                                | Raw Water Storage Impoundment Geotechnical Evaluation               | NAVD                        |

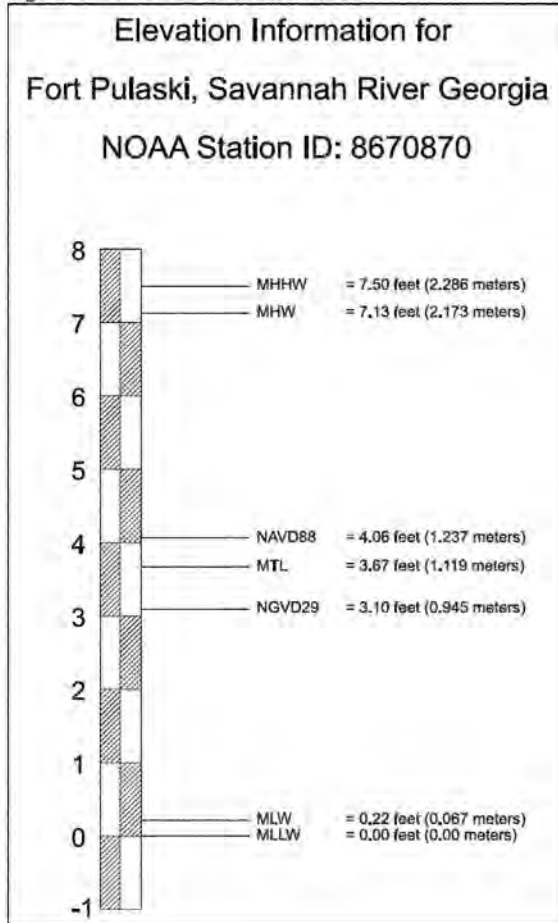
The datum reference is from the NOAA tidal station at Fort Pulaski Savannah River, Georgia (Station ID 8670870). NGVD29 and NAVD88 are both fixed datums. NAVD88 supersedes NGVD29 as the national standard geodetic reference for heights. The tidal datums: MHW (mean high water), MHHW (mean higher high water), MLW (mean low water), MLLW (mean lower low water), and MTL (mean tide level) are determined over a 19 year National Tidal Datum Epoch and are referenced to a local

mean sea level (MSL). The Tidal Datum Epoch for this station is from January 1983 to December 2001. To convert between datums, it is helpful to reference the station datum shown in **Figure 1.3-1**.

To convert elevations between the NGVD29 and MLLW datums use the following equation:

$$\text{MLLW elevation} - \text{difference between MLLW and NGVD29 (3.1 feet or 0.945m)} = \text{NGVD29 elevation}$$

**Figure 1.3-1: Datum Reference Chart**



## 1.4 SOFTWARE VALIDATION

Engineering software used in the SHEP study are technically sound and in accordance with accepted engineering practice. The document and models have undergone many reviews including District Quality Control (DQC), Agency Technical Review (ATR) and an Independent External Peer Review (IEPR). The Quality Control Appendix to the GRR and the SHEP Peer Review Plan discuss the review process in greater detail.

The USACE Enterprise Standard (ES)-08101 *Software Validation for the Hydrology, Hydraulics and Coastal Community of Practice* describes the process for validating engineering software for use in planning studies to satisfy the requirements of the Corps' Scientific and Engineering Technology (SET) initiative and is applicable to all USACE elements having Civil Works responsibility and are using engineering models and analytical tools for planning. The software used in this study that is documented as preferred or allowed for use is listed in **Table 1.3-1** below.

**Table 1.4-1 SHEP Engineering Software and Analytical Tools Documented as USACE Preferred or Allowed for Use**

| Software             | USACE Designation |
|----------------------|-------------------|
| Bentley MicroStation | Preferred         |
| Bentley InRoads      | Preferred         |
| EFDC                 | Allowed for Use   |
| WASP                 | Allowed for Use   |
| HEC-RAS              | Preferred         |
| HEC-DSSVue           | Allowed for Use   |
| ADCIRC               | Preferred         |
| MCACES               | Allowed for Use   |
| ArcGIS               | Preferred         |
| CORPSCON             | Preferred         |
| TABS-MD              | Preferred         |
| SSFATE               | Allowed for Use   |
| STWAVE               | Preferred         |
| WIS                  | Preferred         |
| WISWAVE              | Allowed for Use   |
| GENESIS              | Preferred         |
| UTEXAS3              | Preferred         |
| CADET                | Preferred         |

Software validation and the SET initiative are relatively new and the lists of allowed and preferred models are living documents that are continually being revised and updated. The Engineering and Construction Bulletin outlining the interim guidance on software validation issues for engineering software (ECB No. 2007-6) was issued in April of 2007 well after the SHEP study was underway. Many of the SHEP modeling efforts and impacts determinations began prior to that date and several of the studies were even completed. The PDT has ensured that models chosen for the study are

appropriate for use. None of the models listed as “Not Allowed for Use” on the software validation lists were used for SHEP.

**Table 13.1-2** lists the models utilized in SHEP that are not currently included on the model approval lists developed by the Hydrology, Hydraulics and Coastal Community of Practice (HH&C CoP). Many of these models and study conclusions underwent extensive independent peer review, the results of which are documented in several locations, including the model development reports in the Engineering Investigations Supplemental Materials and the SHEP Peer Review Plan.

**Table 1.4-2 Additional SHEP Engineering Software and Analytical Tools**

| Software                             | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Artificial Neural Networks (ANN)     | ANNs are empirical based data mining and statistical analysis tools. Dr. Bernard Hsieh of USACE ERDC conducted an expert technical review of the ANN used for quantifying chloride impacts in October-December, 2010. Comments resulting from the review were incorporated into the final analysis tool. The ANN was used to confirm chloride impact projections developed through the EFDC and WASP modeling.<br>M2M and MSM are also ANN models and were considered for use early in the study process to quantify environmental impacts to marshes adjacent to the channel due to salinity intrusion. However, use of these models was abandoned when it was discovered that the data mining and extrapolation did not hold true with the flow-altering mitigation features. |
| CSC Virtual Ship 2000 Models         | USACE ERDC Ship Simulator is comprised of Computer Sciences Corporation’s (CSC) Virtual Ship 2000 Models. CSC’s ship models have been fully verified and accepted by leading USCG, US Navy SWOS, and MSC subject matter experts. USACE Engineering and Design Guidance ER 110-2-1403 titled <i>Studies by Coastal, Hydraulic, and Hydrologic Facilities and Others</i> states “studies associated with the planning, design, construction, operation, and maintenance of navigation channels will include a ship or tow simulation investigation”.                                                                                                                                                                                                                              |
| General sand TRANsport Model (GTRAN) | GTRAN is a USACE ERDC developed model that calculates sand transport direction and magnitude under current-dominated and combined wave-current sediment transport regimes. GTRAN uses peer-reviewed published methods for sand transport in these regimes, and automatically determines the appropriate sediment transport formula to use based on the characteristics of the bottom boundary forcing. GTRAN also includes cohesive effects for mixed sediment beds. GTRAN is limited to application outside the surf zone and has been applied by ERDC on several recent studies completed on Savannah Harbor and Tybee Island.                                                                                                                                                |
| D-CORMIX                             | D-Cormix is an EPA supported analytical tool for hydrodynamic mixing zone analysis of continuous dredge disposal sediment plumes. The D-CORMIX model was used in the July 2003 ERDC Nearshore Placement Study to predict loss of sediment during a pipeline placement operation where placement is especially a concern in the nearshore where released sediment could migrate toward the beach.                                                                                                                                                                                                                                                                                                                                                                                |

(Continued on next page)

**Table 1.4-2 Additional SHEP Engineering Models and Analytical Tools (Continued)**

| Software | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DGSLOPE  | DGSLOPE is a slope stability analysis program that was used, along with UTEXAS3, for the 2010 SHEP Bank Stability Report. The program was developed by USACE ERDC and has been widely used throughout USACE.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| DYNCFT   | DYNCFT is a coupled groundwater flow and transport code developed by Camp, Dresser and McKee (CDM) which combines DYNFLOW and DYNTRACK code to simulate the effect on groundwater flow of fluid density gradients associated with solute concentration gradients. The codes have been extensively tested and documented by CDM for over 25 years, reviewed and tested by the International Groundwater Modeling Center (IGWMC, 1985) and evaluated by the ASCE Groundwater Technical Committee (Pandit, 1997). The results of the DYNCFT simulations were reviewed by experts from the USGS, HEC, GA DNR-EPD and SCDHEC, as well as two other independent peer review experts during June-July, 2005 and February-March, 2006. |

The bathymetry data was obtained from several sources because there is not one continuous bathymetry dataset that encompasses the entire system. To simply prescribe a channel design template onto the model grid does not adequately reflect the continuous sedimentation and dredging that is ongoing in the harbor, and is necessary to identify environmental impacts.

The models account for the overdredge volume in the navigation channel by assuming the overdredge is the same in the 42-foot channel (existing conditions) as it would be in any dredged channel depth.

Furthermore, since advance maintenance is proposed to be essentially the same for deepened conditions as for existing conditions, we subtracted 2 feet from the existing (42-foot channel) bathymetry for the 44-foot depth, 3 feet for the 45-foot depth, 4 feet for the 46-foot depth, 5 feet for the 47-foot depth, and 6 feet for the 48-foot depth bathymetry inputs. All depths reference Mean Lower Low Water (MLLW). The reality in the model is that the 48-foot depth is closer to 52 feet which includes the additional depths due to advance maintenance and overdredge.

Overdredging and advanced maintenance are included in all model studies addressing environmental impacts, including hydrodynamic, water quality and hurricane surge models. Non-inclusion of overdredging and advanced maintenance provides a more conservative approach for navigation channel design models (Wave and Current Modeling for Navigation Study, Ship Forces on Shoreline of the Savannah Harbor Project, SHEP Bank Erosion Study). The Impacts on Waves, Currents and Sediment Transport Study is offshore where there is no advance maintenance.



## 2.0 PHYSICAL SETTING

### 2.1 SAVANNAH HARBOR

Savannah Harbor is a deep-draft harbor located on the South Atlantic US coast, 75 statute miles south of Charleston Harbor, South Carolina and 120 miles north of Jacksonville Harbor, Florida. The harbor comprises the lower 21.3 miles of the Savannah River (which, with certain of its tributaries, forms the boundary between Georgia and South Carolina along its entire length of 313 miles) and 11.4 miles of channel across the bar to the Atlantic Ocean.

Within the harbor limits, the Savannah River is generally divided into two channels by a series of islands. From the Atlantic Ocean to River Mile 10 (Station 53+000), where the river converges, the harbor is separated into South and North Channels. Within this area, the navigation channel is maintained in North Channel. After divergence of the river into Front and Back Rivers at River Mile 11 (Station 59+000), the navigation channel is maintained in Front River and passes by the business district of the City of Savannah. The navigation channel is maintained in Front River to the upper limits of the harbor at River Mile 21.3 (Station 112+500). The Atlantic Intracoastal Waterway (AIWW) crosses the navigation channel approximately 5.5 miles upstream of the entrance to the harbor (Station 27+000). The Savannah River Below Augusta Project, which is a shallow-draft navigation channel authorized for 9 ft deep and 90 ft wide, extends upstream from the harbor (River Mile 21.3) to River Mile 202.6 at Augusta, Georgia. See **Figures 2.1-1a** and **2.1-1b**.

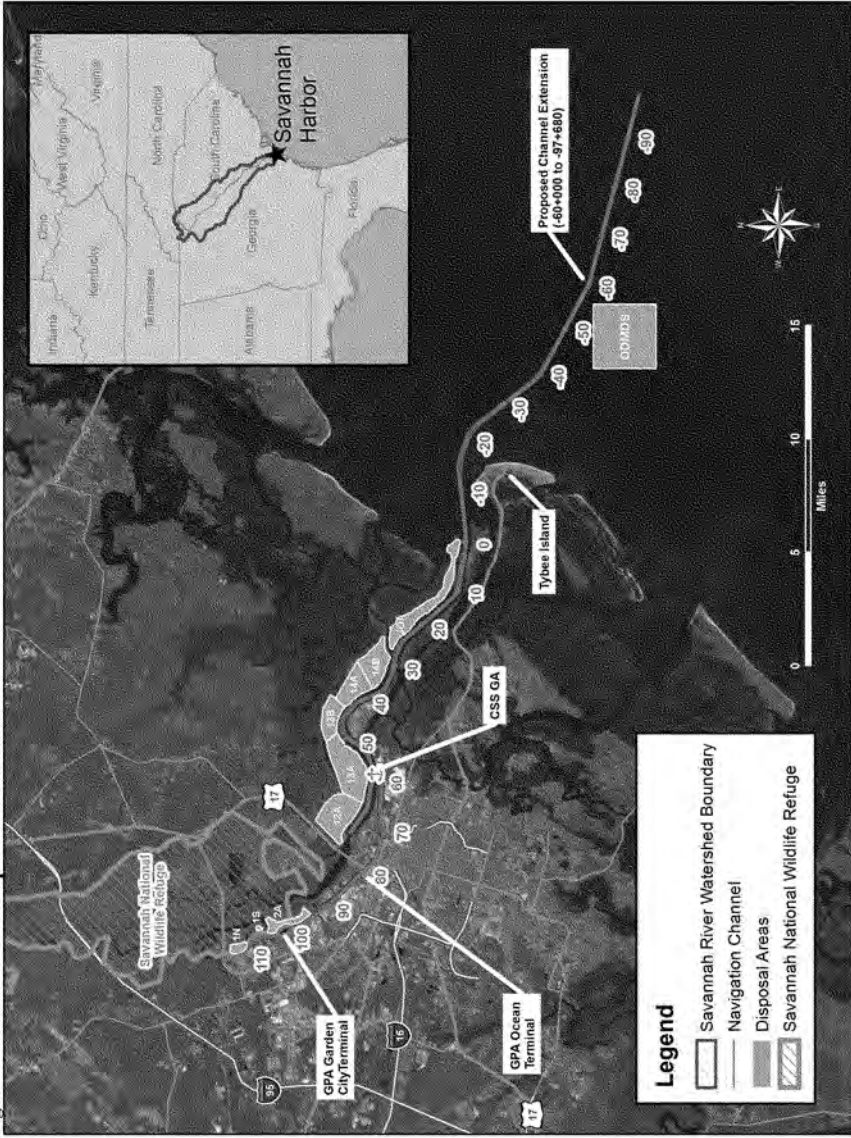
### 2.2 TYBEE ISLAND

Tybee Island, a barrier island located downdrift of the Savannah Harbor navigation channel, loses an estimated 227,000 cubic yards of sand per year from its shelf and shoreline. A study was completed in April 2008 by ERDC titled *Impact of Savannah Harbor Deep Draft Navigation Project on Tybee Island Shelf and Shoreline* that found a significant portion of the loss, 78.5%, is attributed to the maintenance of the navigation channel. This study was funded and performed separately from the SHEP studies. However, results of the study have been considered in the impact analysis for the SHEP, and the report is included in the Engineering Investigations Supplemental Materials. This study indicates that the current entrance channel (including the entrance channel jetties) causes a pattern of ebb shoal deflation on the Tybee Shelf and appears to be nearly a complete sink for any sediment moving from north to south along the Tybee shelf. These studies estimated that the combined shelf and shoreline impact at Tybee Island to be 78.5%. This means that an estimated 78.5% of the reduction in sand volume on the Tybee Island shelf and shoreline can be attributed to the existing project with the remainder of the erosion attributed to natural processes. Any mitigation for this effect would be the responsibility of the existing Savannah Harbor Navigation Project. Despite the impacts to Tybee Island, operation and maintenance of the Federal Navigation Project is expected to continue. This includes all aspects of the project, i.e. the structural features (jetties and advance maintenance areas), the deep-draft navigation channel, and the sediment placement areas. Currently, sediments removed during periodic maintenance of the entrance channel are deposited in the EPA approved Ocean Dredged Material Disposal Site (ODMDS) located approximately 3.7 nautical miles off of Tybee Island.

Renourishment of the Tybee Island shoreline is also expected to continue. The current project authorization is through the year 2024. The renourishment project authorization and funding are not related to the SHEP.

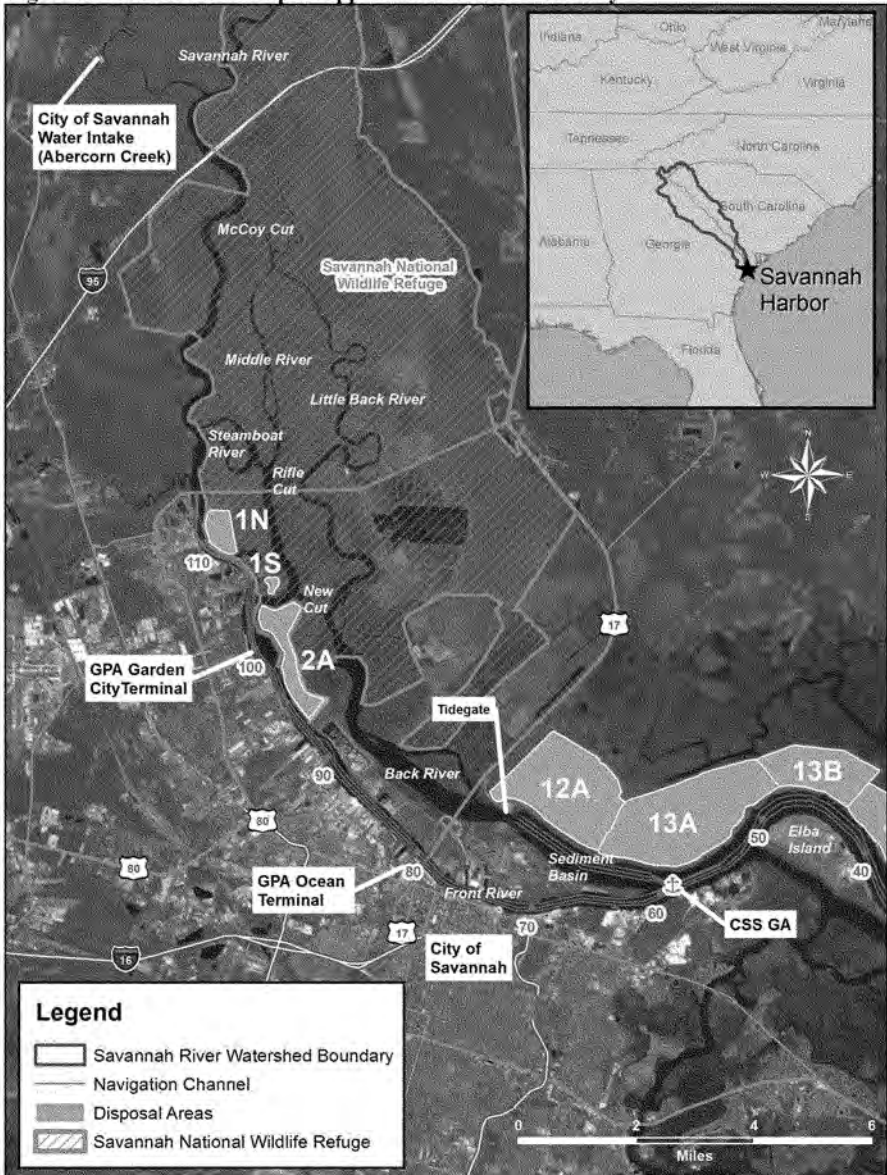


Figure 2.1-1a: Overview Map of Savannah Harbor



Engineering Investigations  
Savannah Harbor Expansion Project

Figure 2.1-1b: Overview Map of Upper Savannah River Estuary



## 2.3 WILDLIFE REFUGES

### 2.3.1 Savannah National Wildlife Refuge

The Savannah National Wildlife Refuge, which is owned and maintained by the US Fish & Wildlife Service, lies on both the South Carolina and Georgia sides of the Savannah River just upriver from the City of Savannah. The refuge was established on April 6, 1927 and consists of 29,175 acres of freshwater marshes, tidal rivers and creeks, and bottomland hardwoods. The refuge includes approximately 6,000 acres of impounded freshwater wetlands for waterfowl habitat. Those impoundments include 3,000 acres which are actively managed by 22 water control structures. Two management schemes are primarily used for the impoundments; drawdown pools and permanently flooded pools. The drawdown pools are drained annually between March 15 and May 15 and manipulated to promote growth of emergent waterfowl food plants. These areas are flooded in the fall of each year. Permanent pools remain flooded all year to promote growth of submerged aquatic plants and to provide wood duck brood-rearing and alligator habitat. Permanently flooded pools are drained, dried, burned, and mowed when undesirable vegetation becomes a problem or productivity of desirable plants decreases. These pools may require additional water at any time to make up for transpiration and evaporation. An adequate supply of fresh water is needed for management of the impoundments. Fresh water is supplied through Lucknow Canal from Little Back River.

Salinity concentrations in the estuary, especially at Lucknow Canal, directly impact the overall health of the ecosystem within the freshwater impoundments of the refuge. High salinity concentrations in the river have the potential to intrude into the freshwater marshes and habitats, making it difficult for freshwater marsh plant species to compete with species more tolerant of brackish conditions.

### 2.3.2 Tybee National Wildlife Refuge

The Tybee National Wildlife Refuge, also owned and maintained by the US Fish & Wildlife Service, was established on May 9, 1938 as a breeding area for migratory birds and other wildlife. The refuge consists of 400 acres of wetlands and diked low lands located at the mouth of the Savannah River across the river from the Fort Pulaski National Monument. Much of the site is diked and is used for placement of sediments dredged from the Savannah Harbor Navigation Project. The vegetated portions of the upland areas are densely covered with red cedar, wax myrtle, and groundsel. Saltwater marsh borders much of the island. The low tide shoreline provides feeding and resting areas for shorebirds and migratory birds. The site is closed to public use.

## 2.4 ESTUARINE CONDITIONS

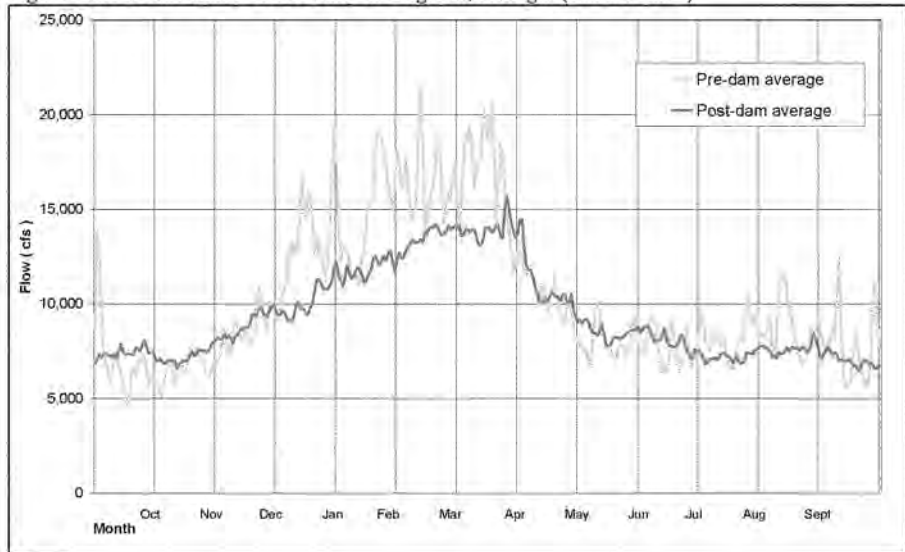
### 2.4.1 Hydrology

The Savannah River drainage basin is over 10,500 square miles and drains lands in North Carolina, South Carolina, and Georgia from three physiographic regions: the Blue Ridge Mountains, the Piedmont, and the Coastal Plain. The headwaters originate in the mountains with the Seneca and Tugaloo Rivers. The confluence of these two rivers forms the Savannah, which flows from Lake Hartwell. There are several reservoirs located on the river in the upper portion of the basin that regulate river flow. Three of these reservoirs are large multipurpose USACE projects, Hartwell Lake, Richard B. Russell Lake, and J. Strom Thurmond Lake. Thurmond Dam is the most downstream

reservoir and is located 220 miles upstream of the mouth of the river near Augusta, Georgia. It was filled in 1954.

Water flow in the Savannah River varies considerably both seasonally and annually even though they are largely controlled by releases of the USACE owned and operated Thurmond Dam. Discharge is typically high in winter and early spring and low in the summer and fall, but regulation by upstream reservoirs has reduced natural flow variations. **Figure 2.4.1-1** below illustrates how river flows have been altered after the dam was constructed. This information is from the USGS gage on the Savannah River at Augusta, GA (Station ID 02197000). The USGS gage on the Savannah River at Clio, Georgia (Station ID 02198500), located approximately 61 miles upstream of the mouth of the river accounts for inflows downstream of Thurmond Dam and is useful in evaluating the freshwater flow coming into the Harbor and estuary. See **Figure 2.4.1-2** for flow data collected at the Clio gage station.

**Figure 2.4.1-1: Savannah River Flow at Augusta, Georgia (1884 to 2001)**



**Figure 2.4.1-2: Savannah River Flow Percentiles at Clyo, Georgia for the Period of Record (1929 to Present)**



## 2.4.2 Tides

Savannah Harbor is located in an area of semi-diurnal tides with two high waters and two low waters each lunar day. A long term tide gage established in 1935 by the National Oceanic and Atmospheric Administration (NOAA) is located at the entrance channel on Cockspar Island near Fort Pulaski (Station ID: 8670870). According to the long term data recorded at the gage, the mean range, the difference between mean high water and mean low water, is 6.92 ft. The diurnal range, the difference between mean higher high water and mean lower low water, is 7.50 ft. The variability in tidal amplitude is due to tidal range cycles between neap and spring tides. Neap tides are periods of lowest tidal amplitude, and spring tides are periods of highest tidal amplitude. Neap tides range between 5 and 6 ft, and spring tides can range upwards of 8 ft.

## 2.4.3 Salinity

Salinity throughout the estuary is highly variable and influenced by the tidal cycle and freshwater inflows. Freshwater flows coming downstream have a dramatic effect on salinity concentrations in the estuary. During very dry and drought conditions, salinity intrudes much further upstream than it does during wetter periods. Data collected during the summer of 1997 result in average bottom salinity concentrations at river mile 4.5 of 24.9 ppt and concentrations at river mile 20.5 of 3.2 ppt.

Salinity concentrations in the estuary have direct influence on the adjacent marshes. A portion of these tidal marshes currently supports freshwater plant and aquatic habitat. As salinity levels in the estuary intrude upstream, the high salinity concentrations in the river have the potential to intrude into the freshwater marshes and habitats, making it difficult for freshwater marsh plant species to compete with species more tolerant of brackish conditions.

The salinity concentrations also vary vertically, through the water column, due to the density of incoming ocean water and tidal mixing cycles. The more dense high concentration saline water coming in with each tide is carried in on the bottom of the water column, while the fresh water coming down the river rides on the top. Because of this stratification of salinity, the salt/fresh interface is known as a saltwater wedge. The saltwater wedge is characterized by high salinity concentrations water on the bottom and near zero salinity concentration on the surface. The prominence of the saltwater wedge is attributable to the tidal amplitudes of neap and spring tides which affects how well the water column is mixed. Greater vertical mixing occurs during spring tides where the amplitude is much higher. This causes the high saline water on the bottom to mix with the fresh water at the surface. The mixing causes less stratification and the saltwater wedge is less apparent. The neap tides, with lower tidal amplitudes, do not produce as much vertical mixing and allow for more stratified conditions with the denser, concentrated ocean water remaining on the bottom of the channel. Neap tidal cycles can cause salinity differences in the water column between surface and bottom to be as great as 17 ppt. Spring tides can reduce the salinity stratification to just 6 ppt.

## 2.5 GENERAL GEOLOGIC SETTING

The study area is underlain with unconsolidated and partly consolidated Atlantic Coastal Plain sediments. These sediments generally consist of unconsolidated to semi-consolidated layers of sand and clay and semi-consolidated to very dense limestone and dolomite and can achieve a thickness of about 5,500 ft. They range in age from late Cretaceous (approximately 65 million years old) to Recent (Holocene). The Atlantic Coastal Plain sediments overlie sedimentary strata and volcanic rocks of Triassic age to early Jurassic age (approximately 230 million years old to about 170 million years old, respectively). These rocks overlie crystalline basement rocks of Paleozoic age (from 680 to 230 million years old) consisting of intrusive igneous and low-grade metamorphic rocks. The rock record is not continuous, and time gaps exist where either no sediment deposition occurred or where erosional events removed the rock record. In the project area, the post-Cretaceous sediments (those deposited within the last 65 million years) are estimated to be about 1,800 to 2,500 ft thick. These strata intersect a horizontal plane in a northeast to southwest trend and dip and thicken to the southeast. For the purpose of this study, the strata will be referred to based on time-rock units (i.e., rocks deposited during the same geologic time division).

### 3.0 CURRENTLY AUTHORIZED PROJECT

#### 3.1 PROJECT DIMENSIONS

The existing authorized Federal Savannah Harbor Navigation Project extends from the seaward end of the entrance channel in the Atlantic Ocean, Station -60+000 up the Savannah River to Station 112+500 (river mile 21.3). The authorized depth for the existing Savannah Harbor navigation project is 42 ft below MLLW in the inner harbor channel and 44 ft below MLLW in the entrance channel. **Table 3.1-1** lists the authorized depths and widths for the existing project located within the limits of the proposed harbor expansion.

The 42-foot project is designed for Panamax vessels drafting 38 ft. However, vessels capable of drafting in excess of 38 ft are presently using the harbor by either light-loading or taking advantage of the considerable tide ranges.

**Table 3.1-1: Currently Authorized Project Dimensions**

| Station            | Authorized Depth<br>(-ft MLLW) | Bottom Width<br>(ft) |
|--------------------|--------------------------------|----------------------|
| Inner Harbor       |                                |                      |
| 103+000 to 102+000 | 42                             | 400                  |
| 102+000 to 100+000 | 42                             | 400                  |
| 100+000 to 79+000  | 42                             | 500                  |
| 79+000 to 70+000   | 42                             | 500                  |
| 70+000 to 50+000   | 42                             | 500                  |
| 50+000 to 41+000   | 42                             | 500                  |
| 41+000 to 24+000   | 42                             | 500                  |
| 24+000 to 0+000    | 42                             | 500                  |
| Entrance Channel   |                                |                      |
| 0+000 to -14+000   | 42                             | 500                  |
| -14+000 to -60+000 | 44                             | 600                  |

Note – Station Numbers are measured in ft from the harbor entrance (Sta. 0+000). Negative numbers indicate the reach is in the entrance channel.

#### 3.2 TURNING BASINS

Five authorized turning basins, shown in **Table 3.2-1**, are located within the reaches proposed for deepening. There is also a private turning basin at Elba Island between the Oysterbed and Fig Island turning basins, which has recently been enlarged and is used by ships delivering liquefied natural gas (LNG) to the LNG facility on Elba Island.



**Table 3.2-1: Currently Authorized Turning Basin Dimensions**

| Name             | Length (ft) | Width (ft) | Authorized Depth (-ft MLLW) | Station           |
|------------------|-------------|------------|-----------------------------|-------------------|
| Kings Island     | 1,600       | 1,500      | 42                          | 101+298 to 97+750 |
| Marsh Island     | 900         | 1,000      | 34                          | 91+610 to 89+485  |
| Fig Island       | 1,500       | 1,000      | 34                          | 69+740 to 67+386  |
| Oysterbed Island | 1,050       | 1,200      | 40                          | 4+395 to 2+345    |
| Rehandling Basin | 5,000       | 300        | 40                          | 10+175 to 4+395   |

### 3.3 SEDIMENT BASIN

The sediment basin is located adjacent to Confined Disposal Facility (CDF) 12A and 13A in the Back River and is an O&M feature that was constructed, along with the Tidegate Structure, between 1972 and 1975 to reduce high shoaling rates along the City Front Reach and provide a safer and more economically maintained navigation channel. Physical model tests were performed prior to construction to determine the effectiveness of the sediment basin. The project was designed to include a set of tidegates that opened on the incoming tide, allowing tidal flushing of the Back River but closed on the outgoing tide, forcing all of the flow through New Cut to Front River and scouring the navigation channel, thus reducing dredging requirements within the navigation channel on Front River. The project was very successful at its intended purpose, but the flow alterations resulted in increased salinity in the Back River. As part of mitigation for the previous harbor deepening, the Tidegates were removed from service in March 1991, and the New Cut, constructed as part of the Tidegate/Sediment Basin project, was blocked off and filled in 1992. However, the sediment basin continues to trap sediments that make their way up Back River.

The sediment basin consists of an entrance channel, or throat, which is 1,600 ft long and 300 ft wide with an authorized bottom elevation of -38 ft MLLW. The basin itself is approximately two miles long and 600 feet wide with an authorized bottom elevation of -40 ft MLLW. Note that these depths do not coincide with the 42 ft authorized depth below MLLW for the navigation channel. The sediment basin was initially dredged in 1972, but regular maintenance of the sediment basin did not begin until 1977. It has not been dredged since 2004 due to funding constraints. Recent surveys of the basin, completed in February 2010, found the bottom elevation to range between 21 and 26 ft below MLLW.

### 3.4 ANNUAL MAINTENANCE

#### 3.4.1 Annual Maintenance Dredging

The inner harbor channel extends from Station 0+000 at the mouth of the Savannah River to Station 112+500, for a distance of 21.3 miles. Currently, the inner harbor channel above Station 28+000 captures all of the clay and silt which enters the estuary from upstream sources. The inner harbor below Station 28+000 shoals with material primarily from ocean sources deposited during slack tide. Approximately 6.2 million cubic yards (cy) of sediments are available to be removed each year from the inner harbor of the Savannah Harbor Navigation Project by USACE. Material dredged from the inner harbor is placed in upland CDFs that have been designed and constructed specifically for maintenance of the navigation channel.



The entrance channel (Stations 0+000 to -60+000) is a sediment sink, which totally interdicts the littoral transport, i.e. it is a trap for all the sediment that is transported to it. Approximately 1 million cy of material are removed from the entrance channel by hopper dredges each year. Currently, this material is placed in the EPA-approved Ocean Dredged Material Disposal Site (ODMDS). The project is also authorized to deposit maintenance sediments in Sites 2 and 3, as well as other designated nearshore sites.

The material dredged from the Savannah Harbor is a mixture of sands, silts, and clays. Sands are dredged from the lower and upper reaches of the project, while the predominant material removed from the middle harbor and sediment basin is silt. The inner harbor sediments are primarily silts and clays from Station 56+000 to Station 103+000. The reach from Station 28+000 to Station 56+000 is a transition reach that has a higher percentage of sand in its distributions than the sediment distributions of the upstream reach. A notable exception is in the vicinity of Station 36+000, which has a high percentage of silts and clays and almost no sand. This location is near the confluence of the inner harbor channel and both Elba Island and Fields Cut. The inner channel sediment distributions from Station 28+000 to the mouth of the Savannah River are primarily sand, which indicates that the source of sediment from this reach is offshore and disposal area erosion. A breakdown of sediment characteristics by dredging reach is shown in **Table 3.4.1-1**.

**Table 3.4.1-1: Sediment Characterization of Annual Maintenance Material by Reach**

|              | Stations            | Sand (%) | Fines (%) |
|--------------|---------------------|----------|-----------|
| Outer Harbor | 0+000 to -10+000    | 86%      | 14%       |
|              | -10+000 to -20+000  | 81%      | 19%       |
|              | -20+000 to -30+000  | 79%      | 21%       |
|              | -30+000 to -40+000  | 77%      | 23%       |
|              | -40+000 to -50+000  | 74%      | 26%       |
|              | -50+000 to -60+000  | 93%      | 7%        |
| Inner Harbor | 0+000 to 4+000      | 90%      | 10%       |
|              | 4+000 to 24+000     | 92%      | 8%        |
|              | 24+000 to 40+000    | 15%      | 85%       |
|              | 40+000 to 50+000    | 30%      | 70%       |
|              | 50+000 to 70+000    | 23%      | 77%       |
|              | 70+000 to 79+000    | 8%       | 92%       |
|              | 79+000 to 97+750    | 16%      | 84%       |
|              | 97+750 to 102+000   | 54%      | 46%       |
|              | 102+000 to 103+0000 | 64%      | 36%       |
|              | 103+000 to 112+000  | 80%      | 20%       |

Sediment characterization is done in accordance with the Unified Soils Classification System per ASTM D2487-00, Standard Practice for Classification of Soils for Engineering Purposes.

Maintenance dredging is performed regularly in the entrance channel and the inner harbor in accordance with the practices and procedures outlined in an Annual Work Plan developed from guidelines set forth in the Dredged Management and Material Plan (DMMP) done in accordance with the Long Term Management Strategy (LTMS). Maintenance dredging in the entrance channel, also known as the bar channel, is performed by hopper dredges that generally work from December through March of each year. Dredging is restricted to this period to minimize the impact dredging has on sea turtles. Material is placed in the EPA approved offshore disposal site. The project is also authorized to deposit maintenance sediments in Sites 2 and 3, as well as other designated nearshore sites. Hopper dredges are generally used in the bar channel because they are designed to withstand open ocean conditions, are well suited for removal of sandy materials deposited in the entrance channel, and can move easily between the navigation channel and open water disposal facilities.

Pipeline dredges perform maintenance dredging in the inner harbor and are designed to remove material with higher silt content using a cutterhead and pump it to adjacent CDFs. Material dredged between Stations 0+000 and 112+500 in the inner harbor is placed in upland CDFs. Dredging upstream of Station 66+310 cannot be performed between March 15 and May 30th of each year. This restriction is imposed by the Georgia Department of Natural Resources to protect the spawning of striped bass in the upper estuary of the harbor. Maintenance dredging is generally being performed in the harbor throughout the year except during restricted times.

Monthly project condition surveys are performed in the navigation channel and turning basins to assist in planning and directing the operation of maintenance dredges. Condition surveys are four profiles run on a monthly basis. These profiles are located on the bottom of the design channel, a specific distance from the toe and centerline on each side of the channel. Thus, there is an inside and outside profile on the north and south sides of the channel. Each of these survey lines are known as "quarters". The results of these surveys are also furnished to the harbor and docking pilots, towing companies, and other navigation and shipping interests. Generally, maintenance dredging is performed when a shoal 2 ft or more above the authorized project depth occurs in any two adjacent quarters of the channel.

Savannah District constructed and operated the tide structure and sediment basin in the Back River between 1974 and 1991. This feature shifted a significant portion of the shoaling from the navigation channel in the Front River to the sediment basin in the Back River. After construction of the sediment basin and tidegate structure, the river channel shoaling volume between Stations 40+000 and 70+000 was reduced by 2 million cubic yards. The majority of this material shoaled in the sediment basin.

In 1992, New Cut, which was the connecting channel between the Front and Back Rivers, was closed as a separately authorized Section 1135 project. The sediment basin continues to trap maintenance material and is periodically dredged. However, its efficiency has been reduced with the closure of New Cut and removal of the tidegates. The remainder of the material shoals in the navigation channel. Material is easily removed from the sediment basin and is placed in adjacent CDFs at a considerable cost savings compared to the cost of removing material from the navigation project, due to the reduced pumping distance. Due to funding constraints, the sediment basin has not been dredged since 2004.

Several reaches in the inner harbor are considered to have rapid shoaling. Advance maintenance is authorized in the harbor to reduce the frequency of dredging in areas with additional depth in these rapid shoaling areas. Advance maintenance is the additional depth beyond the authorized project dimensions which is required to be dredged for the purpose of reducing overall maintenance costs by decreasing the frequency of dredging. Without this practice, it would be difficult and more costly to

provide a navigable project for deep draft vessels. The shoaling locations in the navigation channel have changed since New Cut was closed, and the tidegates were taken out of operation and the need for additional advance maintenance was evaluated. The Kings Island turning basin functions as a sediment trap in the upper reaches of the harbor and an additional 8 ft of advance maintenance was approved and dredged. The locations and depths of approved advance maintenance are shown in **Tables 3.4.1-2 and 3.4.1-3.**

**Table 3.4.1-2: Currently Authorized Channel Dimensions (Including Advance Maintenance)**

| Station            | Authorized Depth (-ft MLLW) | Bottom Width (feet) | Advance Maintenance (feet) | Maintenance Dredging Depth (-ft MLLW) |
|--------------------|-----------------------------|---------------------|----------------------------|---------------------------------------|
| Inner Harbor       |                             |                     |                            |                                       |
| 103+000 to 102+000 | 42                          | 400                 | 0                          | 42                                    |
| 102+000 to 100+000 | 42                          | 400                 | 2                          | 44                                    |
| 100+000 to 79+000  | 42                          | 500                 | 2                          | 44                                    |
| 79+000 to 70+000   | 42                          | 500                 | 2                          | 44                                    |
| 70+000 to 50+000   | 42                          | 500                 | 4                          | 46                                    |
| 50+000 to 41+000   | 42                          | 500                 | 4                          | 46                                    |
| 41+000 to 37+000   | 42                          | 500                 | 4                          | 46                                    |
| 37+000 to 35+000   | 42                          | 500                 | 6                          | 48                                    |
| 35+000 to 24+000   | 42                          | 500                 | 4                          | 46                                    |
| 24+000 to 0+000    | 42                          | 500                 | 2                          | 44                                    |
| Entrance Channel   |                             |                     |                            |                                       |
| 0+000 to -14+000   | 42                          | 500                 | 2                          | 44                                    |
| -14+000 to -60+000 | 44                          | 600                 | 0                          | 44                                    |

**Table 3.4.1-3: Currently Authorized Turning Basin Dimensions (Including Advance Maintenance)**

| Name                                | Length (feet) | Width (feet) | Authorized Project Depth (-ft MLLW) | Advance Maintenance (feet) | Maintenance Dredging Depth (-ft MLLW) |
|-------------------------------------|---------------|--------------|-------------------------------------|----------------------------|---------------------------------------|
| Kings Island<br>101+298 to 97+750   | 1,600         | 1,500        | 42                                  | 8                          | 50                                    |
| Marsh Island<br>91+610 to 89+485    | 900           | 1,000        | 34                                  | 0                          | 34                                    |
| Fig Island<br>69+740 to 67+386      | 1,500         | 1,000        | 34                                  | 4                          | 38                                    |
| Oysterbed Island<br>4+395 to 2+345  | 1,050         | 1,200        | 40                                  | 0                          | 40                                    |
| Rehandling Basin<br>10+175 to 4+395 | 5,000         | 300          | 40                                  | 0                          | 40                                    |

Note: Station Numbers are measured in feet from the harbor entrance (Sta. 0+000). Negative numbers indicate the reach is in the entrance channel.

### 3.4.2 Annual Maintenance Disposal Facilities

#### 3.4.2.1 Upland Confined Disposal Facilities (CDFs)

Material dredged in the inner harbor navigation channel, turning basins, the sediment basin, and berthing areas is placed in upland confined disposal facilities adjacent to the river. These disposal facilities are regularly maintained and upgraded based on disposal capacity needs projected in the Long Term Management Strategy (LTMS), the 1995 document which established the approved methods for harbor maintenance. These CDFs are located in Chatham County, Georgia and Jasper County, South Carolina. The Georgia Department of Transportation is the local sponsor responsible for providing and maintaining these areas in concert with the USACE, Savannah District.

**Table 3.4.2.1-1** shows the location of each CDF relative to the navigation channel stations. Station numbers followed by "BR" are located adjacent to the Back River (sediment basin). The site acreage shown in the table describes the interior footprint of the disposal areas; it does not describe the total area including the dikes. Details of each CDF and location follow the table. See **Figure 3.4.2.1-1** for a location map.

**Table 3.4.2.1-1: Upland Confined Disposal Facilities**

| Area                  | Station (feet)         | Site Acreage |
|-----------------------|------------------------|--------------|
| 1N                    | 107+500 to 112+500     | 130          |
| 2A                    | 93+000 to 103+000      | 240          |
| 12A                   | 6+500 BR to 10+500 BR* | 1040         |
| 13A                   | 47+800 to 6+600 BR*    | 1307         |
| 13B                   | 42+000 to 47+800       | 540          |
| 14A                   | 37+000 to 42+000       | 647          |
| 14B                   | 28+000 to 37+000       | 765          |
| Jones/Oysterbed (JOI) | 0+000 to 27+000        | 890          |

\*BR refers to Back River or that portion of the channel located in the Back River (sediment basin).

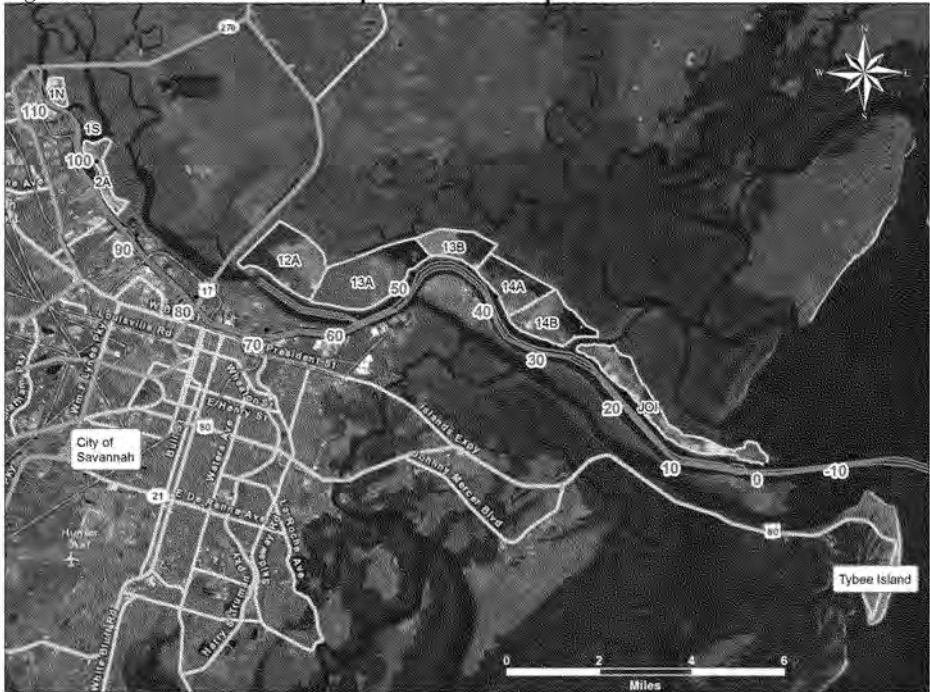
**Disposal Area 1N** – Disposal Area 1N is the uppermost disposal area in the harbor. It is owned by USF&W and currently contains medium to coarse grained sand. The USACE has limited rights for disposal to this area. All dredged material pumped to the area must be predominantly sand. It will not be utilized during the SHEP.

**Disposal Area 2A** – The dikes in Disposal Area 2A have recently been raised, and capacity is designated for annual maintenance material. Once this capacity is used, the dikes will no longer be able to be raised due to the overhead power lines which cross the center of the area. There is insufficient clearance between the top of the dike and the low-point (sag) of the power lines to safely operate equipment required to maintain and raise the dikes. In 2009, Area 2A entered a three year drying phase which coincides with construction of the deepening project. Therefore, it will not be utilized for SHEP disposal.

**Disposal Areas 12A, 13A, 13B, 14A, and 14B** – These five disposal areas are all diked and are contiguous. They are located from south of Highway 17 east along the Back and Front Rivers. Areas 12A and portions of 13A are adjacent to the Sediment Basin on Back River. Areas 12B and 13A were recently combined by breaching the cross dikes during a scheduled dike raising. Construction was completed in 2010, and the area is now designated as Area 13A. Area 14B receives dredged material from both the Savannah Harbor Navigation Project and the Atlantic Intracoastal Waterway (AIWW). During the SHEP construction, 13A, 14A, and 14B are planned for utilization for disposal of new work material.

**Jones/Oysterbed Island** – Jones/Oysterbed Island (JOI) Disposal Area is the easternmost upland CDF used for dredging. This area will be utilized for SHEP disposal of new work material.

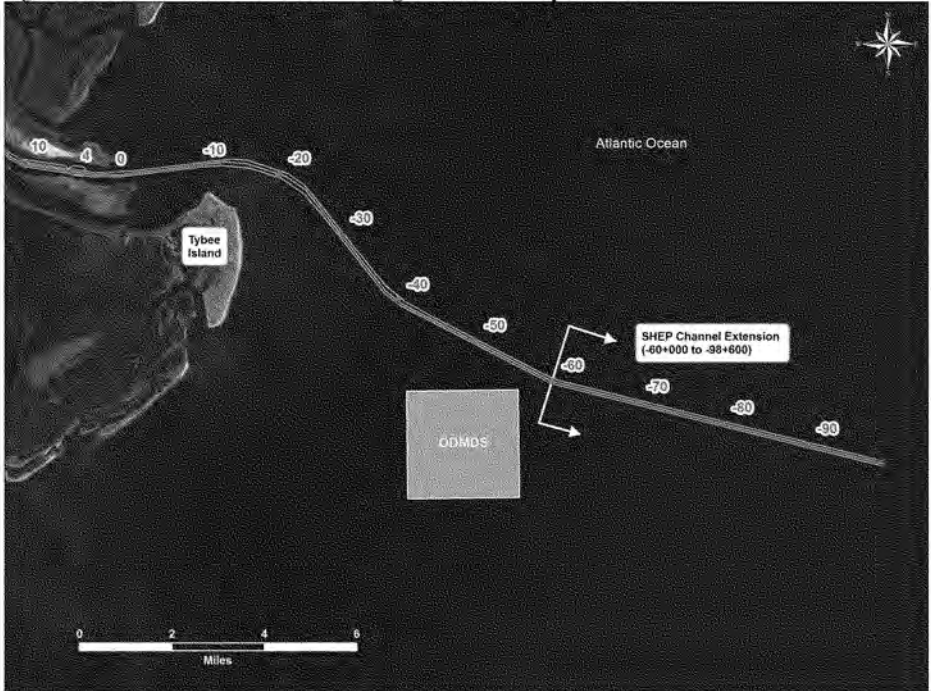
**Figure 3.4.2.1-1: Savannah Harbor Upland Confined Disposal Areas**



### 3.4.2.2 Open Water Dredged Material Disposal Areas

Annual maintenance material removed from the Entrance Channel (Stations 0+000 to -60+000) is placed in the EPA-approved Ocean Dredged Material Disposal Site (ODMDS). This 4.26 square nautical mile site is centered at 31° 56' 54" N and 80° 45' 34" W and is shown in **Figure 3.4.2.2-1**. The site is used for placement of the 1 million cubic yards of material that is removed by hopper dredges each year from that channel reach. The final designation of the site as an ODMDS was made by EPA on August 3, 1987.

**Figure 3.4.2.2-1: Location of Ocean Dredged Material Disposal Site**





### 3.5 OBSTRUCTIONS AND CROSSINGS

Two significant cultural resources exist adjacent to the navigation channel between Stations 59+000 and 58+000. Old Fort Jackson is a masonry civil war structure located on the south side of the river. The banks upstream and downstream of Old Fort Jackson have a history of erosion problems. On various occasions since the 1970's, the USACE has pumped dredge material around the fort to raise the ground elevation to reduce flooding, placed riprap on the riverbank adjacent to the fort property, and constructed a steel sheet pile wall at the intake structure which controls the flow of water into the moat. The moat wall sits on the riverbank and has been hit by a ship on one occasion. The most recent protection work was completed in May 2004 as an authorized Section 111 project. Work included construction of a steel sheet pile wall on the river side of a portion of the moat and placement of riprap on the downstream side of the fort.

The remains of the CSS Georgia, a civil war ironclad, are located on the north slope of the navigation channel across from Old Fort Jackson. Over the last decade, maintenance dredging operations have been modified to lessen impacts to the remains of the ironclad. Recent archaeological studies have concluded that the remains need to be removed from the channel to preserve what is left before it is totally destroyed by boring worms and corrosion, the effects of which were escalated after a maintenance dredge impacted the site of the wreck in 1983.

In addition to the cultural resources adjacent to the channel, there are submerged pipe crossings, one highway bridge, and an overhead electric power line which cross the navigation channel within the proposed expansion limits. None of these structures presently impacts performance of maintenance dredging in the project. Dredges are required to exercise extreme care, however, when dredging in the vicinity of the pipelines. Dredges are not allowed to set anchors and/or drop spuds near the identified submerged structures when they are performing maintenance dredging. Dredging inspectors constantly monitor the position of the dredge and the dredge anchors when contractors work in this area.

### 3.6 MILITARY RAPID DEPLOYMENT

The Port of Savannah is one of the thirteen strategic seaports designated to support deployment of selected armed forces combat units and support elements. The Port of Savannah is the designated Sea Port of Embarkation for vehicles and equipment from the 3<sup>rd</sup> Infantry Division (Mechanized) at Ft. Stewart and elements from Hunter Army Airfield and the 24<sup>th</sup> Infantry Division, Ft. Benning. The military vessels that are used for deployment at the port include large roll-on/roll-off fast sealift ships that are 946-ft long with a loaded draft of 37 to 38 ft. Since emergency deployment can occur at any time, it is vital to national security that the navigation channel, turning basins and designated container berths at Garden City Terminal are maintained at an adequate depth to accommodate these vessels. There is no alternative port of embarkation for deployment by these installations.

## 4.0 SITE GEOLOGY

### 4.1 GEOLOGIC SETTING

Eastern Chatham County is underlain by approximately 2,000 ft of sedimentary Coastal Plain sediments ranging in age from Holocene to Cretaceous. From land surface to a depth of about 500 ft, these sediments consist of unconsolidated to somewhat indurated beds of sand and clay of Recent (Holocene) and Miocene age to indurated limestones of Oligocene and Eocene age. The Oligocene and Eocene limestones comprise what is commonly referred to as the Upper Floridan aquifer.

Within the study area, the elevation of the top of the Oligocene unit, the uppermost unit of the Upper Floridan aquifer, ranges from roughly -95 ft MLW near Tybee Island to approximately -200 ft MLW near downtown Savannah. The top of the Miocene unit occurs at an average of about -45 ft MLW with generally little relief within the study area, and unit thickness ranges from less than 30 ft near Tybee Island to 160 ft near downtown Savannah. **Figure 4.1-1** shows a geologic cross section along the Savannah River navigation channel.

In this study, the Tybee high is the structural feature of most importance, namely where the tops of the Miocene confining unit and the Oligocene unit are nearest land surface. Over the crest of the Tybee high, the elevations of the top of the Oligocene unit range from -95 ft MLW beneath Tybee Island to -115 ft MLW at the channel at Fields Cut, and the Miocene unit is generally exposed in the bottom of the navigation channel. Proposed dredging operations associated with the Savannah Harbor Expansion Project could lower the channel depth to as much as -57 ft MLLW (for the 47 ft project depth) in certain locations, specifically Kings Island Turning Basin. In the harbor vicinity, this stratigraphic horizon is composed of Pleistocene-Recent and Miocene sediments.

### 4.2 HYDROGEOLOGIC SETTING

The Floridan aquifer system underlies parts of Alabama, Georgia, South Carolina, and Florida and supplies approximately 50 percent of the groundwater in Georgia. The aquifer system is divided into two major aquifers: the Upper Floridan and Lower Floridan. Within Chatham County and the study area, the Upper Floridan aquifer is the primary source of groundwater and supplies approximately 30 percent of the total water supply in Chatham County.

Prior to development, the flow system was considered steady state, i.e. recharge was equal to natural discharge (artesian springs, streams, etc.), and water levels showed little fluctuation from year to year. However, development within the coastal region and the associated increased groundwater withdrawal has unbalanced the recharge and discharge rates. This increased pumping has lowered water levels, induced additional recharge and reduced natural discharge, and increased total flow through the system.

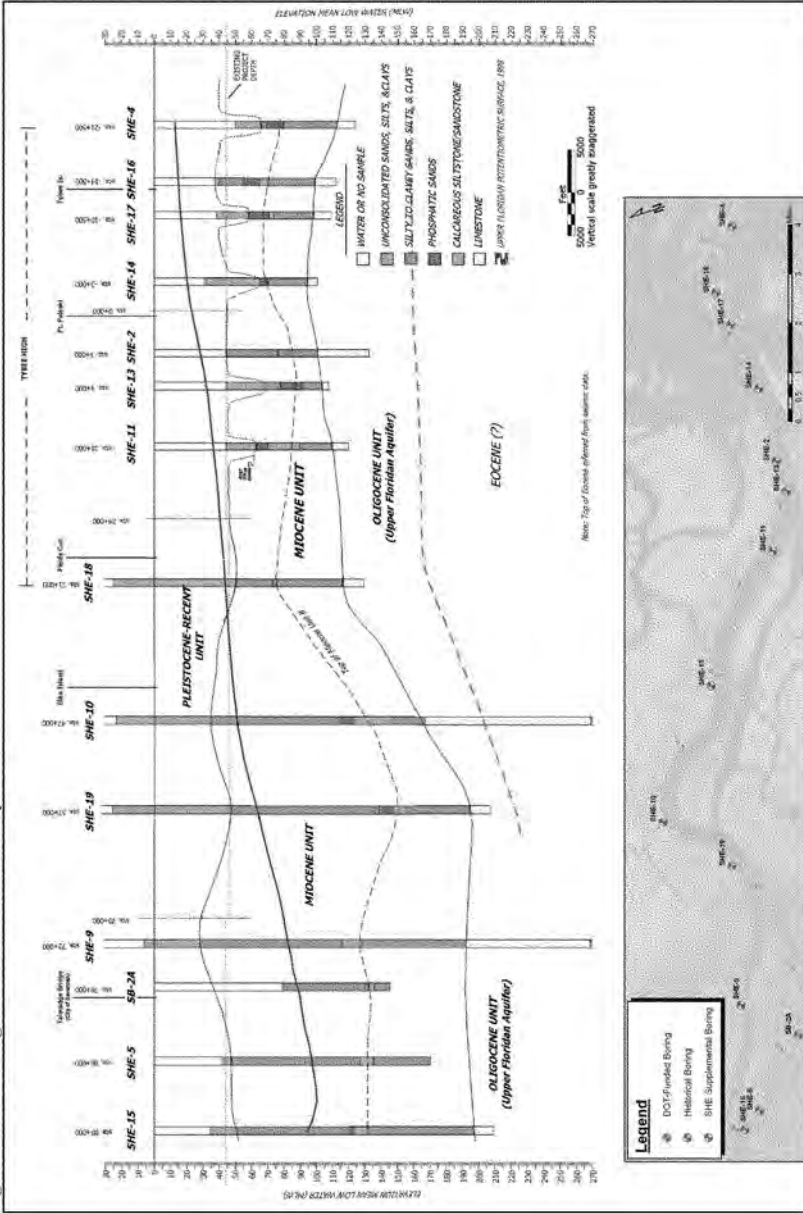
The long-term pumping of the Upper Floridan aquifer in the Savannah area and surrounding coastal areas has lowered groundwater levels and reversed the seaward hydraulic gradient that existed before development. The increased withdrawal of water from the Upper Floridan aquifer has resulted in radial flow directed toward the center of pumping and a cone of depression beneath Savannah. Prior to development, heads in the Upper Floridan aquifer ranged from 20 to 150 ft above sea level in southeast Georgia and from 30 to 50 ft above sea level in Chatham County. In contrast, in May of 1998, Peck



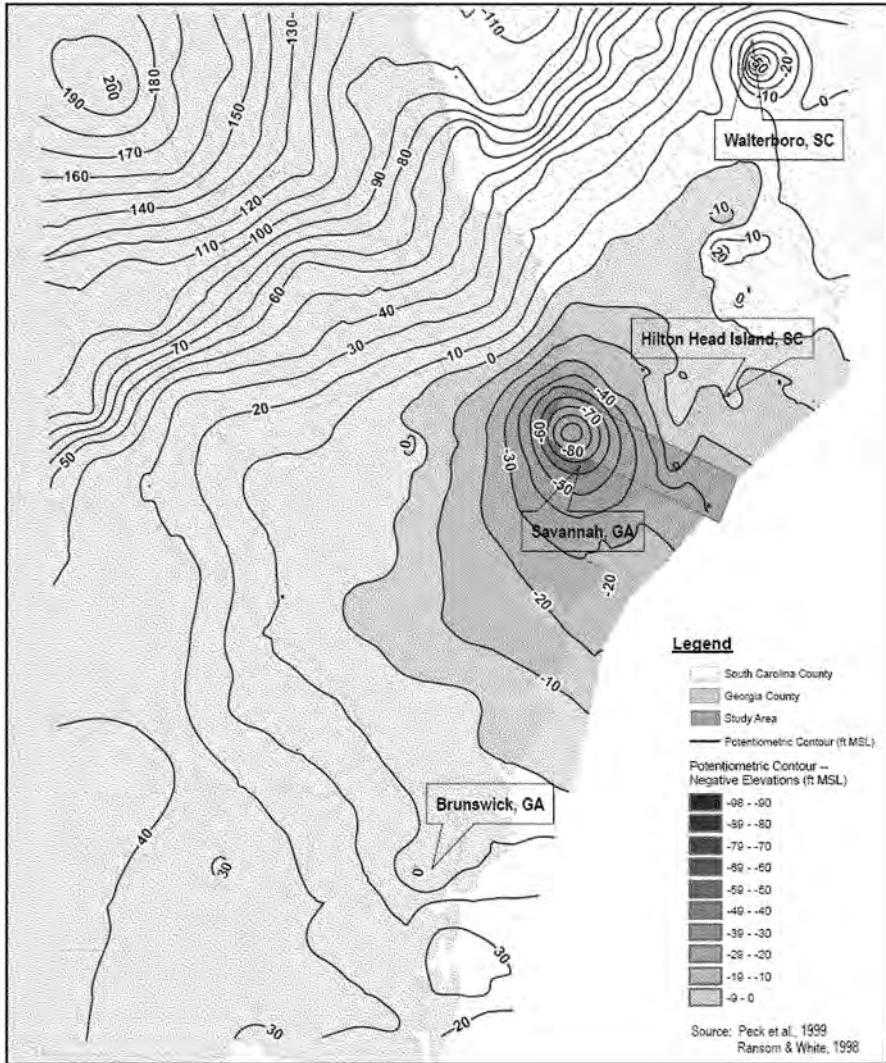
reported a maximum head of 60 ft above sea level occurring south of Brunswick and maximum drawdown occurring near the city of Savannah, where heads ranged from -10 ft to -100 ft below mean sea level (**Figure 4.2-1**).

This reversal in hydraulic gradient has resulted in lateral encroachment of seawater and downward vertical intrusion of salt water through the confining unit. Vertical leakage of water through the confining unit contributes a significant amount of water to the flow system in the study area; in fact, the leakage through the upper confining unit has been estimated to represent nearly half the water budget for the Savannah area, or about 40 million gallons per day (MGD). The aquifer effects supplemental study examines the impact of the proposed dredging on the rate of vertical intrusion, which consist of both fresh and salt water, and the resulting groundwater impacts in the Upper Floridan aquifer. The results of this study are summarized in Section 5.0 and documented in full in the report entitled *Supplemental Studies to Determine Potential Groundwater Impacts to the Upper Floridan Aquifer* which is included in the Engineering Investigations Supplemental Materials.

Figure 4.1-1: Geologic Cross Section of Study Area



**Figure 4.2-1: Potentiometric Surface of the Upper Floridan Aquifer in the Coastal Area, 1998**



### 4.3 GEOLOGIC AND HYDROGEOLOGIC UNITS

This study focused on the hydrogeology of sediments underlying the present navigation channel, specifically the upper 150 to 200 ft, which encompasses the Oligocene, Miocene, and Pleistocene-Recent units. In the Savannah Harbor area, the geologic formations can be grouped into three broadly defined hydrogeologic units: the Upper Floridan aquifer, the Miocene confining unit, and the surficial aquifer.

#### 4.3.1 Upper Floridan Aquifer

In the coastal area, the Upper Floridan aquifer consists of limestone of Late Eocene and Oligocene age and is characterized as vuggy and highly fossiliferous. The Late Eocene unit consists of massively bedded, fossiliferous limestone and dolomite that contains bryozoans, foraminifera, and mollusk shells. The Oligocene unit unconformably overlies the Late Eocene unit and consists of buff-colored, porous limestone with foraminifera, zones of micrite, and nonparticulate phosphate. The Oligocene unit is distinguished from the Late Eocene unit by its lack of bryozoans and its abundance of miliolid foraminifera.

The elevation of the top of the Upper Floridan aquifer (Oligocene) is approximately -200 ft MLW under the city of Savannah, and the contact gently slopes upward to the east toward Tybee Island. Over the crest of the Tybee high, the top of the Upper Floridan aquifer is closer to land surface and is typically around -100 ft MLW in elevation. In the study area, the Upper Floridan aquifer is 150 to 250 ft thick, and the uppermost two zones, zone 1 and zone 2, are the most productive. Zone 1 and zone 2, approximately 44 ft and 35 ft thick, respectively, combine to supply more than seventy percent of the water pumped from open holes tapping the entire aquifer. Pumping reached a maximum of 88 MGD in 1990 and has since slightly declined due to a reduction in industrial pumping. In the year 2000, Chatham County withdrew approximately 72 MGD from the Upper Floridan aquifer.

Transmissivity of the Upper Floridan aquifer is highly variable in the coastal area, and in the area between Port Royal Sound, South Carolina and Savannah, the transmissivity varies from 27,000 ft<sup>2</sup>/d to 80,000 ft<sup>2</sup>/d. The transmissivity in the Savannah area is low in comparison with other areas along the coast (27,000 ft<sup>2</sup>/d to 33,000 ft<sup>2</sup>/d). The low transmissivity has resulted in a substantially deeper cone of depression as compared with other major pumping centers with similar withdrawal rates.

#### 4.3.2 Miocene Confining Unit

Strata of Miocene age in the coastal area have been differentiated into the Ebenezer Formation (upper Miocene), the Coosawhatchie Formation (middle Miocene), and the Marks Head and Parachula Formations (lower Miocene); three depositional sequences of similar lithology each bounded by unconformable contacts. Hydrogeologists refer to the units collectively as the “confining bed” or “confining unit” overlying the Upper Floridan aquifer. In the Savannah area, the Miocene sediments unconformably overlie limestone of Oligocene age, establishing a lithologically and geophysically distinctive contact.

The confining unit is a series of lithologically complex sequences of predominately clastic sediments containing low-permeability clays, silts, clayey silts and sands, and clayey or silty sands. Each sequence comprises a geologic unit that consists of a basal carbonate layer, a middle clay layer, and an upper sand layer and is bounded above and below by an unconformity. These units were each defined

by persistent geophysical markers designated as A, B, and C and are basal contacts for each of the Miocene units, referred to as upper, middle, and lower Miocene, respectively.

In the project area, Miocene units A and B occur, and Miocene unit C is generally absent or eroded such that only the basal carbonate layer remains and is indistinguishable from the basal contact of unit B. Miocene units A and B consist of green-colored, silty clay and clayey or silty sands underlain by a basal dense, phosphatic limestone or dolomite. Underneath the navigation channel, the basal contacts range in thickness from less than 1 foot to 10 ft thick, and the overall thickness of the confining unit (units A, B, and C) ranges from about 30 ft thick near the Tybee high to over 150 ft thick near downtown Savannah.

### 4.3.3 Pleistocene-Recent Unit

The shallow sands and clays that occur from land surface to a depth of typically 60 to 75 ft, but locally as much as 130 ft, comprise the Pleistocene-Recent unit. The Pleistocene-Recent unit overlies the Miocene unit in the project area, and the contact is marked by an erosional unconformity, which is sharp in some areas but gradational in others.

Pleistocene to Recent sediments in the Savannah area consist of phosphatic, micaceous, and clayey sand of Pliocene age; arkosic sand and gravel containing discontinuous clay beds of Pleistocene age; and mud, sand, and gravel of Holocene age. Although the geometry and lithologies of these Pleistocene-Recent sediments are geologically complex, with typically lenticular bodies of sand or clay, aquifer sands near the base of the Pleistocene are laterally persistent although not necessarily continuous throughout the coastal region.

Along the present day navigation channel, the Pleistocene-Recent sediments range from 0 to 30 ft thick and are predominantly composed of clays and silts. Depositional environments of the Pleistocene-Recent unit within the Savannah River corridor include off-channel deposits of sands and clays and in-channel deposits of fluvial sands, silts, and clays (paleochannels).

Groundwater within the surficial aquifer occurs under both unconfined (water table) and confined (artesian) conditions in the coastal zone. In places, a basal Pleistocene sand, typically about 15 to as much as about 40 ft thick, is separated from an upper fine-grained sand by a low-permeability dark-gray clay. These sands are recharged by local rainfall, and groundwater moves laterally with typically very low hydraulic gradients toward local streams and tidal water bodies. In the Savannah area, daily combined withdrawals from the upper and lower water-bearing zones range from 120,000 to 855,000 gallons per day.

## 4.4 SUMMARY OF MATERIALS TO BE ENCOUNTERED DURING DREDGING

### 4.4.1 General

The sediments underlying the project area are largely a result of varying depositional environments. As such, the sediments are discontinuous both vertically and horizontally and numerous variations occur over short distances. Boring logs completed for these investigations are included in the *Dredged Material Physical Analysis Report* that is included in the Engineering Investigations Supplemental

**Materials.** The report also includes laboratory results of the mechanical analyses of the samples collected during these investigations and a boring plan of all borings drilled in Savannah Harbor.

#### 4.4.2 Soil

Sediment characterization is done in accordance with the *Unified Soils Classification System* per ASTM D2487-00, *Standard Practice for Classification of Soils for Engineering Purposes*.

The uppermost recent sediments consist of varying mixtures of poorly-graded sands (SP), silty sands (SM), poorly-graded gravels (GP), organic silts (OH), low liquid-limit and high liquid-limit silts (ML and MH), clayey sands (SC), and low liquid-limit and high liquid-limit clays (CL and CH). Standard penetration tests from borings indicate the consistency of the fine-grained soils (silts and clays) range from very soft (0 to 4 blows per foot) to very dense (50 or greater blows per foot), while the coarse-grained soils (sands and gravels) range in consistency from dense (30 to 50 blows per foot) to very dense (50 or greater blows per foot). Typically, these soils vary in color from tan, gray, brown, light brown, and greenish to bluish gray. Generally, soils at the river bottom exhibit lower consistency than the deeper soils. The bottom soils are often very loose and semi-liquid and can extend from the bottom of the river channel to only a few inches to several feet deep.

The underlying Miocene-aged soils consist of silty sands (SM), clayey sands (SC), high liquid-limit silts (MH), and low liquid-limit and high liquid-limit clays (CL and CH). Standard penetration tests indicate the consistencies of the fine-grained soils range from stiff (8 to 15 blows per foot) to hard (30 or greater blows per foot), while the coarse-grained soils range in density from dense (30 to 50 blows per foot) to very dense (50 or greater blows per foot). In general, these soils are characterized by a significant increase in blow counts, uniform consistency, and cohesiveness. These soils are often described as grayish green, green, olive gray, and olive green.

#### 4.4.3 Rock

Lenses of moderately hard to hard limestone have been encountered in borings around the project area; however, its occurrence has been below the depths of concern for this project. In addition, borings drilled in 1969 identified compaction shale in the northern end of the channel, near Kings Island turning basin. This lithology has not been identified in any of the more recent borings, and this material may be analogous to the greenish-gray to olive green, stiff to hard, fat silts and dense to very dense silty sands that have been described in later borings.

A high resolution, subbottom seismic survey was performed in the channel during the early 1990's as part of the investigation program for the previous harbor deepening to -42 ft MLW. This survey showed an area of high acoustic impedance within the middle channel (Stations 70+000 to 24+000). Borings drilled in this area and subsequent dredging indicated this material was similar to the greenish-gray to olive green, stiff to hard, fat clays and dense to very dense silty sands described above.

Thin layers of rock were identified in a 2002 boring at the interface between the post-Miocene sediments and the top of the Miocene. The layer was no more than a few centimeters thick and was a green, fine-grained, sandstone. These more recent borings also describe black gravels and oblong rock fragments within the Miocene sediments, consistent with the geological descriptions of the Miocene phosphatic marker beds provided above in Section 4.3.2. These materials were encountered both within and below the project depth.

## 4.5 SUBSURFACE INVESTIGATIONS

### 4.5.1 Aquifer Effects Evaluation Supplemental Study

#### 4.5.1.1 Purpose and Scope

The methods employed in the current aquifer study were intended to build and expand on the information from previous studies, particularly the 1998 *Potential Groundwater Impacts* for the Savannah Harbor Expansion Feasibility Study that was prepared as part of the Tier I EIS. Following the release of the 1998 study, the Savannah District, with input from the United States Geological Survey (USGS), Georgia Environmental Protection Division (GAEPD), South Carolina Department of Health and Environmental Control (SCDHEC), and the Stakeholders Evaluation Group (SEG), developed a conceptual plan and work outline to address comments from the 1998 report and establish new supplemental study objectives.

The principal objective of the current study was to determine how much proposed dredging activities would contribute to increased chloride levels in the Upper Floridan aquifer and evaluate the associated impacts on aquifer water quality. Based on the 48 ft depth alternative, the proposed dredging activities to deepen the navigation channel would impact materials contained between -42 ft and -58 ft MLLW, which is comprised primarily of Miocene-aged sediments. Consequently, the study focused on the Miocene-aged upper confining unit (i.e. confining layer) along the navigation channel, especially from Fields Cut to approximately two miles offshore of Tybee Island, where the confining layer naturally thins and relict channels have cut further down into the confining layer as shown in **Figure 4.5.1.1-1**.

The Savannah District Geology/Hydrogeology, and HTRW Design Section evaluated the study objectives according to six major tasks that included completing additional seismic surveying, conducting additional land and marine drilling that incorporated porewater and hydraulic testing, developing a groundwater model, determining the feasibility of conducting an aquitard test, and incorporating data, past and present, into a comprehensive Geographic Information System (GIS). The results and conclusions are discussed in Section 5.0, and the complete report entitled *Supplemental Studies to Determine Potential Groundwater Impacts to the Upper Floridan Aquifer* is included in the Engineering Investigations Supplemental Materials.







#### 4.5.2 Environmental Sediment Quality Evaluation

Sediment quality evaluation was conducted between geologists and biologists to determine environmental implications. Details for the full evaluation can be found in the EIS. A summary of those findings is found below.

In 1997, sediment core samples were collected and examined for sediment physical and chemical properties. The sampling area covered the entire project area proposed for harbor deepening, extending from deep water in the ocean to the Kings Island Turning Basin (Station 103+000). Parameters investigated included metals, PCBs, PAHs, petroleum hydrocarbons, phenols, pesticides, dioxin congeners, cyanide, organotins, and nutrients. The evaluation found that most of the sediments did not provide any concern for potential contaminant-related impacts associated with the proposed dredging and dredged sediment placement. However, three potential issues were identified.

One issue involved sediments near the old RACON Tower site. Subsequent sampling conducted in 2005 revealed that sediments at that location do not pose a potential for contaminant-related environmental impacts.

The second issue pertained mostly to whether the sediment chemistry data for pesticides, PAHs and phenols, especially achieved detection limits, were adequate for comparison to screening criteria. This issue was addressed during the 2005 sampling. The confirmatory sampling within the channel revealed there are no potential sediment contaminant concerns related to pesticides, PAHs, phenols, or metals other than cadmium.

The final issue involved the concentration and distribution of cadmium within the new work sediments. Sampling was conducted in 2005 to address this issue. Cadmium was found to occur naturally in unusually high levels within Miocene soils that would be excavated during the SHEP dredging. Evaluation of the laboratory results could not rule out the potential for adverse impacts from sediments with elevated cadmium levels in some reaches of the channel. Therefore, additional sampling and detailed analyses were conducted in 2007. The potential pathways by which cadmium might enter the environment were evaluated. Pathways of particular concern were identified to be exposure of cadmium-containing clays within the channel with subsequent movement of cadmium into the river ecosystem, and potential environmental impacts associated with placement of cadmium-containing sediments within the confined disposal facilities (CDFs).

The recommendations resulting from these evaluations are as follows:

New work sediments from the reaches 6+375 to 45+000, 51+000 to 57+000 and 80+125 to 90+000 should be isolated within a CDF and capped/covered with sediment from another reach. The high cadmium sediments should not be disturbed further and should not be allowed to be later excavated and placed in any exposed upland area.

Once a CDF is selected to receive the sediment, the high cadmium sediments should be pumped into the area first. Once placement of sediments from this reach is completed, markers should immediately be placed on the surface of the sediment, to allow easy determination of when the proper cap/cover depth has been attained. At least 1 foot of additional sediment from another reach should then be placed in the area as soon as practicable, but as part of the SHEP, to ensure minimal environmental impacts from birds feeding within the CDF. Due to expected variability in construction techniques, the

project design will use 2 ft of capping/covering sediments. Details of the disposal plan for cadmium sediments are discussed further in Section 11.0.

### 4.5.3 Radiological Screening

#### 4.5.3.1 Purpose

The project area is located downstream from the Savannah River Site, where radioactive materials are processed. Releases of radioactive materials from the site have been documented over the years, raising concern as to whether such releases could cause accumulation of these materials within the sediments that are to be removed from the project area. The likelihood of this occurring has been considered improbable; nevertheless, a decision was made to screen selected sediment samples that were collected during the 2002 investigations for gross radioactivity. The complete report is included as part of the *Dredged Material Physical Analysis Report* included in the Engineering Investigations Supplemental Materials.

#### 4.5.3.2 Procedures

All samples collected during the 2002 subsurface investigations were placed in sample jars, labeled, inventoried, boxed, and shipped to the US Army Corps of Engineers, Savannah District Environmental and Materials Unit located in Marietta, Georgia. Prior to performing the mechanical analyses, randomly selected jar samples from each borehole were screened for gross radioactivity. This process involved using a Bicron Geiger-Mueller gauge equipped with a pancake probe. The probe was placed approximately 1 centimeter above the soil samples, and the highest reading was recorded. Readings were also collected from around the facility to determine ambient background levels.

#### 4.5.3.3 Results and Conclusions

All results were measured in milli-Rems per hour (mRem/hr). Background values varied between 0.01 and 0.03 mRem/hr. Values from the sediment samples ranged from 0.02 to 0.04 mRem/hr. These results are consistent with the background values, with only a few samples exhibiting an increase of 0.01 mRem/hr over the background range. The slight increase in some samples was expected, as the soils encountered are known to contain phosphatic and glauconitic minerals, along with other clays, that exhibit naturally-occurring radiation levels above background. The results are two magnitudes below acceptable action levels approved by OSHA and the EPA that range between 1 mRem/hr and 5mRem/hr. Based on these results, it is believed that the levels of gross radioactivity measured in the samples is naturally occurring and poses no hazard to the environment.

## 5.0 INVESTIGATIONS OF IMPACTS TO THE UPPER FLORIDAN AQUIFER

### 5.1 PROCEDURES

The methods employed in the aquifer study were intended to build and expand on the information from previous studies, particularly the internal studies done by the Savannah District and USGS Bulletin 113 by Clarke et al. The Savannah District used input from various agencies including the USGS, GAEPD, SCDHEC, SEG, and GPA to develop a scope of work for the supplemental studies. The study was implemented according to six tasks (**Table 5.1-1**), each of which is summarized below. Detailed methods for each task are included in the report *Supplemental Studies to Determine Potential Groundwater Impacts to the Upper Floridan Aquifer*, which is included in the Engineering Investigations Supplemental Materials.

**Table 5.1-1: Tasks Comprising Aquifer Effects Evaluation Supplemental Studies**

| Task | Subject                       | Description                                                                                                                                                                                                                                                                                                                           |
|------|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1    | Subbottom Seismic Survey      | Conduct additional subbottom seismic surveying with particular emphasis to better define paleochannel geometry and Upper Floridan confining unit thickness. All seismic data will be acquired in digital format to facilitate analysis and storage in the GIS.                                                                        |
| 2    | Marine Drilling               | Conduct additional marine continuous core borings to further characterize in-filled sediments of paleochannels and Miocene confining unit below paleochannels.                                                                                                                                                                        |
| 3    | Land Drilling                 | Conduct additional continuous core borings on land adjacent to navigation channel to top of Upper Floridan aquifer at three strategic locations where geologic or hydrogeologic data is sparse.                                                                                                                                       |
| 4    | GIS                           | Combine existing geologic, hydrogeologic, seismic, and engineering data from previous studies into the harbor-wide GIS being constructed for Savannah Harbor. Add future supplemental data to the GIS to allow enhanced analysis and visualization.                                                                                   |
| 5    | 3-D Numerical Hydraulic Model | Develop 3-D coupled flow and transport model of the hydrologic system focused on the navigation channel, and use model to compare before and after dredging results as related to projected chloride changes in the Upper Floridan aquifer.                                                                                           |
| 6    | Aquitard Test Feasibility     | Conduct trial step-drawdown pumping test on two recently installed Upper Floridan wells located adjacent to river channel to determine feasibility of hydraulic testing of confining unit. If results indicate hydraulic testing of confining unit is feasible, estimate design parameters and assumptions for full aquitard testing. |

Ocean Surveys, Incorporated (OSI) performed a supplemental subbottom geophysical survey to fulfill requirements outlined in Task 1. The survey served as an addition to the extensive work completed in 1997, in which relict paleochannels and the underlying stratigraphy were defined along the centerline of the navigation channel. OSI conducted the supplemental survey along the sides of the navigation channel between River Stations 30+000 to -30+000, where the majority of paleochannels cut across the navigation channel, in an effort to better determine the orientation of the paleochannels and the thicknesses of the underlying units.

Seven marine continuous core borings were drilled adjacent to the navigation channel, six of which were drilled in known paleochannels, to fulfill the requirements outlined in Task 2. The cores were drilled to the top of the Upper Floridan aquifer to further define the stratigraphy underlying Savannah harbor. Each core was drilled using fresh water and analyzed for porewater geochemistry, geophysical markers, grain size, porosity, and vertical hydraulic conductivity.

Similar to Task 2, Task 3 entailed drilling two additional land borings in an effort to complete the geologic transect along the entire length of the navigation channel. The borings were strategically drilled in areas where geologic or hydrogeologic data was sparse, and core samples were analyzed for porewater geochemistry, geophysical markers, grain size, porosity, and vertical hydraulic conductivity. In addition, the data from the borings will be used to install two sets of multi-level wells near existing Upper Floridan wells. The wells will be installed within the surficial aquifer and the Miocene confining unit and will be used to collect hydraulic head and groundwater data at discrete depth intervals over long periods of time.

The porewater geochemistry methods employed in this study were developed over the past ten years by researchers and scientists that have extensive sub-surface knowledge of the coastal region. The innovative technique allowed Savannah District scientists to evaluate dredging effects based on an unprecedented amount of actual field data, not just assumed or estimated values. For each boring, samples of porewater, water contained within the pore spaces of a geologic material, were collected at regular intervals from, at minimum, the top of the confining unit to the top of the Upper Floridan aquifer. Several sampling methods were employed to collect in-situ porewater at discrete depths throughout the confining unit. The porewater samples were then analyzed for concentration of several dissolved ions, including chloride. The resulting concentrations were then plotted according to the depth at which they were collected, yielding profiles of chloride concentration within the confining unit versus elevation for each boring location.

Task 4 concerned the development of a comprehensive harbor-wide GIS. Specifically, the task aimed to compile existing geologic, hydrogeologic, seismic, and engineering data from available historical reports published by the Savannah District, USGS, GAEPD, SCDHEC, or otherwise into a comprehensive GIS for enhanced analysis and visualization.

Task 5 entailed developing a three-dimensional (3-D) numerical hydraulic coupled flow and transport model of the hydrologic system in the immediate vicinity of the navigation channel. The Savannah District issued a contract to CDM to perform this task. The modeling software used for the study is called DYNCFIT, which includes applications from DYNFLOW and DYNTRACK. The model incorporated hydraulic properties, confining unit thickness, and historic and present pumping rates to determine a range of plausible aquifer responses to deepening the navigation channel. Simulations were run according to a no dredging scenario and a worst-case dredging scenario, where "worst-case" refers to a maximum project depth of -48 ft MLW, the associated overdredging allowances, and a three

foot disturbance depth. The model outputs were compared to evaluate the potential effects of dredging on water quality in the Upper Floridan aquifer.

Task 6 was intended to be a trial pumping test on two existing Upper Floridan wells in order to determine the feasibility of performing an aquitard test on the confining unit. Prior to conducting this task, several model simulations were performed to check the validity of previous results from pumping tests conducted at the Tybee Island test well cluster. Since the Tybee Island tests and the model simulations indicated a full aquitard test would likely require months to pump millions of gallons of water from the aquifer to acquire potentially little meaningful data, full aquitard testing was not felt to be warranted. Further details on the simulated pump tests are included in the complete report, *Supplemental Studies to Determine Potential Groundwater Impacts to the Upper Floridan Aquifer*, which is included in the Engineering Investigations Supplemental Materials.

## 5.2 RESULTS

The detailed study approach allowed for a greater understanding of the geologic and hydrogeologic framework underlying the navigation channel. Measured porewater data, hydraulic conductivity data, head data, seismic data, and confining layer thickness data were used to build upon a regional model built by USGS and refine it to address water quality issues specifically associated with dredging impacts. In order to ensure the groundwater model results were conservative, the dredging scenarios were run assuming an additional three feet of material would be removed below the proposed dredging depths. In addition, the model simulations used two values of hydraulic conductivity that provided two sets of results that bracketed true conditions, yielding best-case and worst-case scenarios for both dredging and no dredging conditions. Selected results are summarized below. Detailed results for each task are included in the report *Supplemental Studies to Determine Potential Groundwater Impacts to the Upper Floridan Aquifer*, which is included in the Engineering Investigations Supplemental Materials.

### 5.2.1 Porewater Profiles

The porewater data derived from this work indicate that, as expected, seawater is moving downward through the Miocene confining layer toward the Oligocene limestone (Upper Floridan aquifer), and in some locations, low concentrations of chlorides appear to have migrated entirely through the confining layer and into the limestone. The pronounced profiles show that chloride concentration decreased with depth from the top to the bottom of the confining layer, and chloride values ranged from a high of 20,000 mg/L near the top of the layer to a low of 15 mg/L near the bottom of the layer. The data also suggest somewhat enhanced leakage of salt water in areas where deep paleochannels cut across the present navigation channel that are underlain by punctuated decreases in chloride concentration below the Miocene unit A contact. **Figure 5.2.1-1** shows a geologic cross section of borings completed and their corresponding chloride porewater profile curves.

### 5.2.2 Geophysical Survey

The subbottom seismic survey provided a comprehensive data set of the stratigraphy underlying the navigation channel within the area of concern (River Stations 30+000 to -30+000). The seismic profiles generated from the survey were used to better understand the three dimensional relationship of the navigation channel, paleochannels, and the confining layer. A typical plan and cross section illustrating the relationship between the navigation channel and paleochannels is shown in **Figure**

**5.2.2-1.** In general, subbottom data indicated that the paleochannel features identified in the entrance channel are oriented oblique to the present-day course of the river. The subbottom data indicated that the minimum thickness of Miocene confining material underlying the navigation channel was about 26 ft near Station 9+000.

### 5.2.3 Groundwater Model

The groundwater model results indicated that the expected increase in downward volume of flow of saline water from the area underlying the Savannah River navigation channel due to dredging is small. The area affected by dredging accounted for a total downward flow between 50 to 250 gallons per minute depending on the hydraulic conductivity assigned to the Miocene confining unit. Dredging the navigation channel increased the total downward flow between 2 to 7 gallons per minute, or 3 to 4 percent. The contribution is negligible when compared to groundwater production in the Savannah area from the Upper Floridan aquifer, which is on the order of 80 million gallons per day (55,555 gallons per minute).

The concentrations presented represent only the contribution from the river and navigation channel. Other salt water sources (salt marshes, offshore) were not included as part of simulating the explicit impacts of dredging.

**Figure 5.2.3-1** shows plan view simulated chloride concentrations in the Upper Floridan aquifer for the years 2000, 2050, and 2200 for both dredging and no dredging scenarios. The distributions indicated that chloride plumes tend to move parallel to the river due to the groundwater flow direction induced by heavy pumping near downtown Savannah. Thus, the concentration results discussed above are relevant only for chloride concentrations directly below the river. Simulated impacts north or south of the river dissipated over a relatively short distance. The simulated chloride concentrations in the Upper Floridan aquifer using the mid-range value of hydraulic conductivity showed negligible difference between the dredging and no dredging scenarios.

In the year 2200, the upstream chloride concentrations in the Upper Floridan aquifer beneath the river were defined as approximately 0 mg/L for low-value hydraulic conductivity simulations and up to 100 mg/L for the mid-range hydraulic conductivity simulations. Downstream, chloride concentrations directly beneath the river approached 500 mg/L after 200 years for the low-value hydraulic conductivity simulations. For the mid-range hydraulic conductivity simulations, total breakthrough (equilibrium) occurred after approximately 100 years, and the maximum chloride concentration (1,400 mg/L) in the Upper Floridan aquifer occurred in the downstream portion of the study area.

In the upstream reaches of the river, where the surface water model predicted minimum increases in chloride concentrations, the differences in chloride concentrations in the top of the Upper Floridan aquifer between the dredging and no dredging scenarios were minor. Downstream, where higher surface water chloride concentrations were predicted to occur, the corresponding differences in concentrations in the Upper Floridan aquifer directly below the river ranged from 10 to 200 mg/L and were typically observed 50 or more years into the future. These concentrations represent only a small percentage of the total concentrations expected in the aquifer, thereby yielding the contribution from dredging to the total concentration in the aquifer insignificant when compared with the combined chloride contributions from other salt water sources.



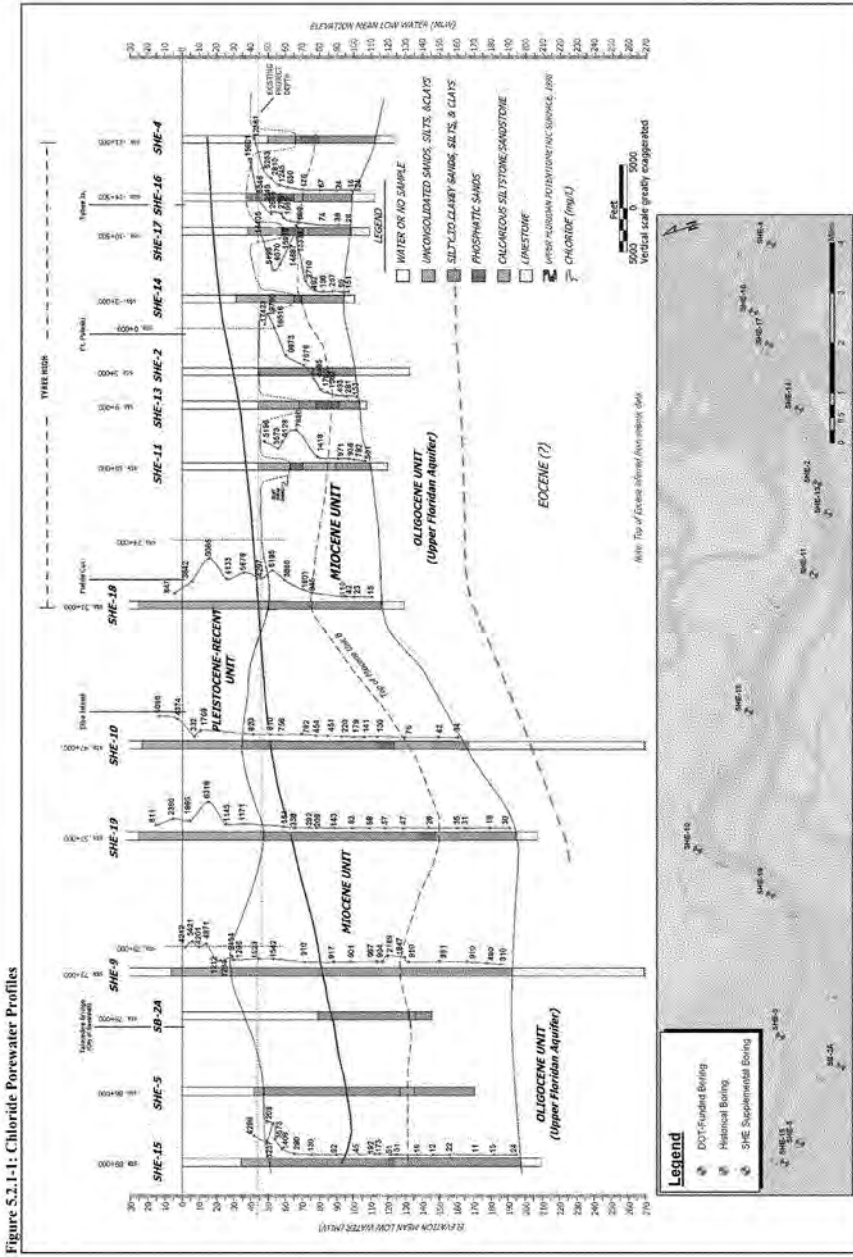






Figure 5.2.2-1: Paleochannel Orientation and Contact Correlation with Borings

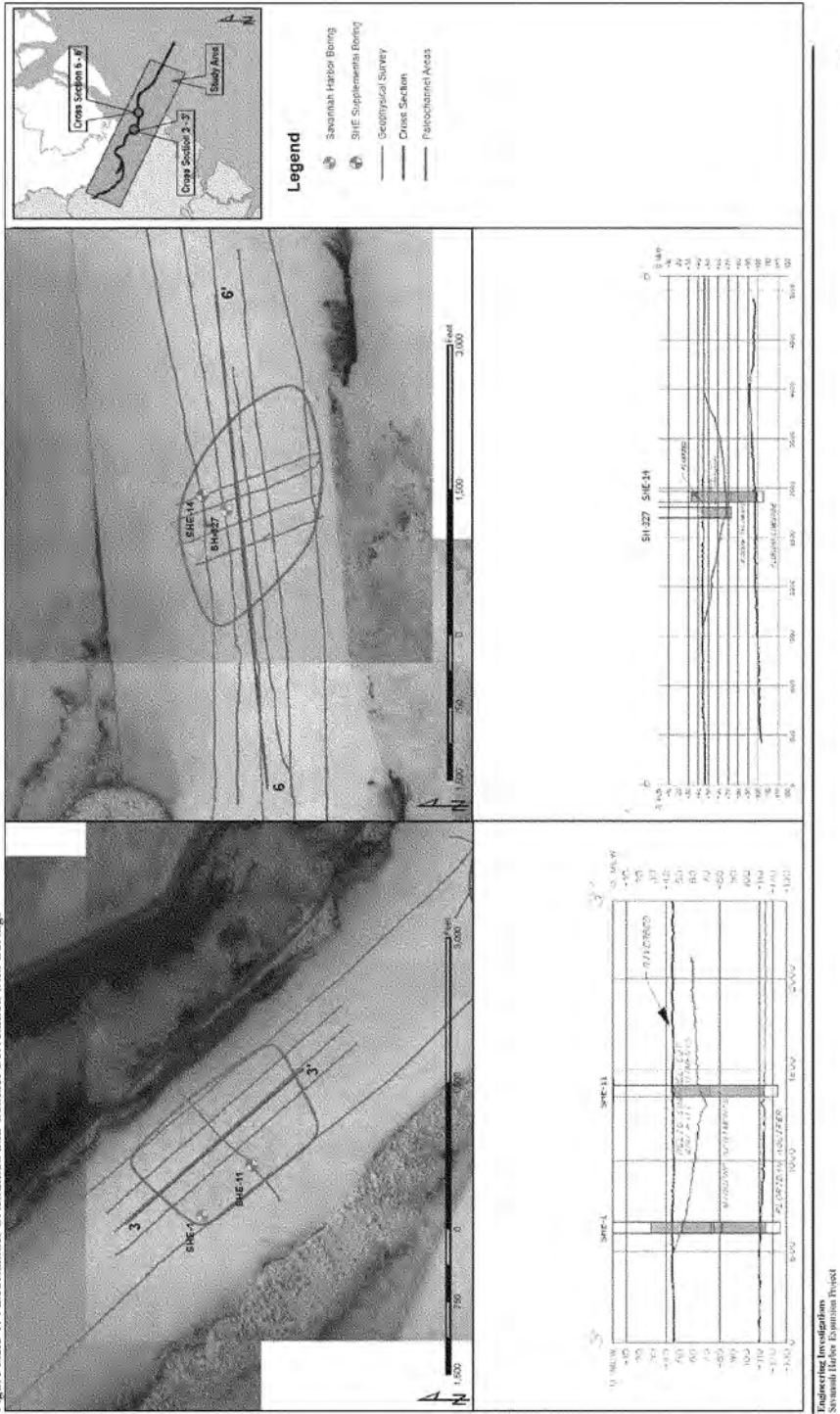
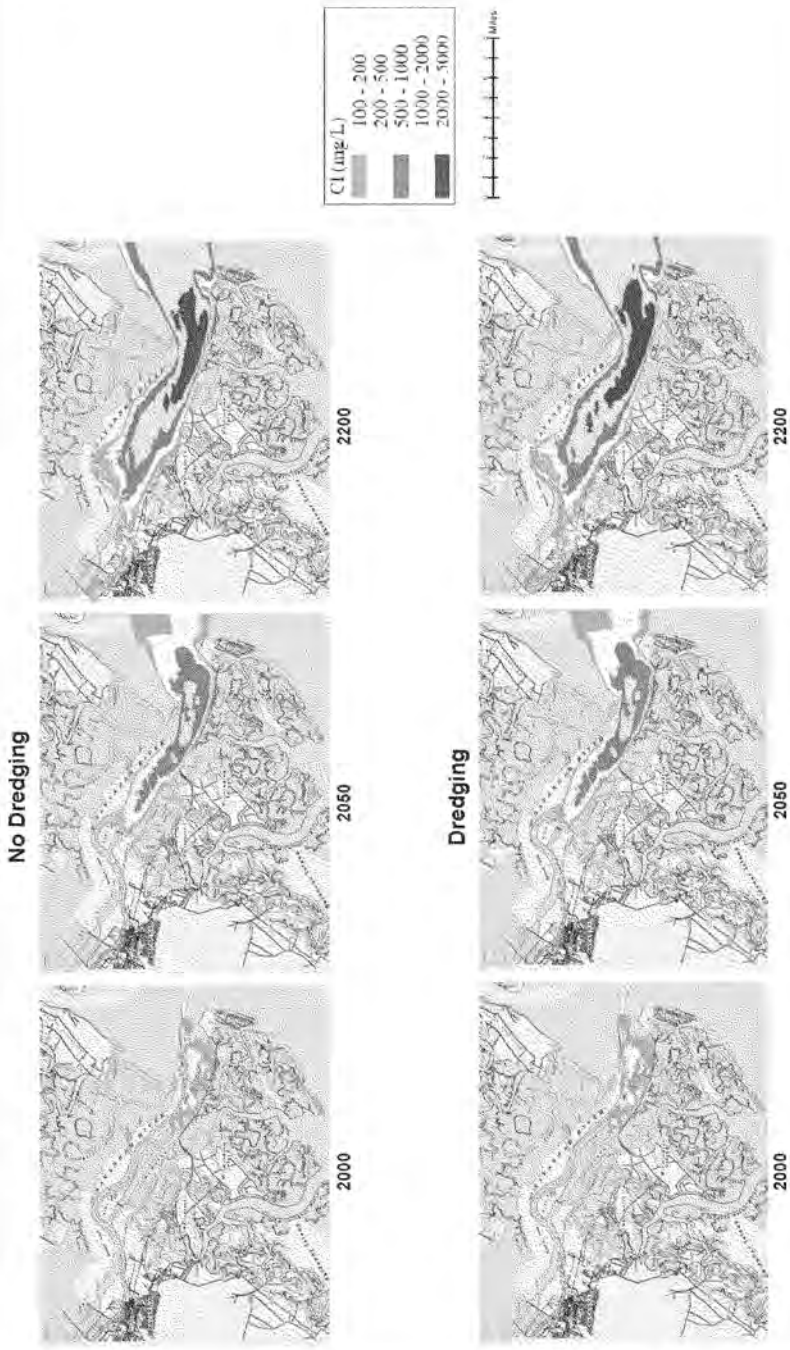




Figure 5.2.3-1: Chloride Distributions in the Upper Floridan Aquifer





### 5.3 CONCLUSIONS

The results from field work, groundwater modeling, and GIS analyses conducted as part of the supplemental aquifer study provided the most comprehensive picture of the geology and hydrogeology underlying the Savannah River to date. The conclusions and recommendations listed below are based on compiled historic data as well as data collected specifically for the supplemental studies. Whenever applicable, conservative assumptions were applied in order to ensure recommendations were based on a worst-case impact.

A site-specific seismic subbottom survey was performed from River Station 30+000 to -30+000, and the results of the survey provided detailed stratigraphy and information about all major paleochannels within the area of concern. The location, attitude, and extent of all paleochannels were mapped and incorporated into the Miocene surfaces created for the GIS and the groundwater model to determine their role in potential dredging impacts. Groundwater model results indicated that any additional contribution of chloride by the paleochannels is negligible when compared to the total contribution from other adjacent salt water sources outside paleochannels along the river bottom. The impacts of dredging on the in-fill sediments of the paleochannels, which were simulated in the model to represent sand, were small when compared to the impacts of dredging elsewhere in the channel where the Miocene confining unit is impacted. GIS analyses indicated that the minimum thickness of the Miocene confining material occurs where paleochannels have incised into the top of the unit, and the proposed dredging activities would not further impact the Miocene confining layer in these areas.

All model results and concentrations reported are based on chloride concentration effects specifically associated with dredging the navigation channel. They do not account for other salt water sources including salt marshes or the Atlantic Ocean. As such, the values reported *do not* represent total concentrations or distributions expected; they represent the contribution from the river and navigation channel to the total concentration. This contribution is a small percentage when compared to the total concentration expected from other salt water sources.

The location of the maximum negative head gradient, i.e. the center of the cone of depression, poses the largest potential for enhanced salt water leakage through the confining layer. The porewater data and model results, however, showed that the thickness of the confining unit (>100 ft) and the lower salinity of the river water at this upstream location minimize this impact in the upstream reaches of the navigation channel and production wells located in and around Savannah.

The downstream areas, however, specifically near the Tybee high, showed a gradual increase in chloride concentrations in the Upper Floridan aquifer ranging from 500 to 1400 mg/L depending on hydraulic conductivity of the confining layer. The enhanced salt water intrusion in this area is attributed to a combination of factors: the induced negative head gradient from pumping in Savannah; the overlying seawater or saline water with minimal freshwater input from the Savannah River; the naturally thin confining layer (40-60 ft); and the paleochannels that have further removed Miocene material.

Although lab results indicated that zones within the paleochannel fill material have comparable hydraulic conductivities to the Miocene material, porewater profiles constructed within paleochannels suggest that they still have some influence on the rate of salt water intrusion. The porewater profiles also showed that chloride concentrations decrease rapidly below the Miocene contact. This punctuated reduction in concentration supports the notion that dredging paleochannel material would have

minimal effect on the downward rate of salt water intrusion. Additionally, if the paleochannel material were not considered “confining”, then dredging in these areas would not reduce the thickness of the underlying confining unit. Instead, the potential impacts on water quality due to dredging should focus on the entire thickness of material overlying the aquifer and the amount of Miocene-aged material removed.

Near the Tybee high, the aquifer is predominantly overlain by seawater, and the Miocene confining layer is thin. These two naturally occurring factors significantly contribute to the enhanced salt water intrusion in the area and locally affect water quality in the Upper Floridan aquifer. However, the model results showed that the proposed dredging would have little effect on this process. The groundwater model results showed that, in the year 2200, the concentration increase in the navigation channel due to dredging translated to only a small increase in the aquifer directly below the navigation channel (10-200 mg/L dependent on hydraulic conductivity). Production wells located in the downstream reaches of the river showed negligible differences between the dredging and no dredging scenarios, and the contribution to total chloride concentrations increased by a range of 0 to 50 mg/L after 200 years.

The groundwater model simulations were run 200 years into the future with a constant pumping rate in the Savannah area, and the results indicated that this rate of pumping would cause total breakthrough of seawater to occur *regardless of dredging* at some downstream locations in approximately 100 to 300 years depending on hydraulic conductivity of the confining layer.

In summary, the negative head gradient induced by pumping in Savannah has caused limited breakthrough of chlorides to occur in the downstream reaches of the Savannah River. The porewater profiles and model results from this study indicated that increased salinity in the Savannah River and the reduced thickness of the confining layer due to dredging will not significantly affect the timing of breakthrough of chlorides along the navigation channel in the Upper Floridan aquifer. Furthermore, the aquifer study results showed that the proposed dredging would have minimal impacts on water quality in production wells that tap the Upper Floridan aquifer in and around the city of Savannah.

## 6.0 CHANNEL DESIGN

The Channel Design Drawings, including typical sections, are located in Attachment 1 to the Engineering Investigations Appendix.

### 6.1 DESIGN VESSEL

The post-Panamax S-class containership, the *Susan Maersk*, was chosen as the design vessel for the Savannah Harbor Expansion Project in September 2001. The *Susan Maersk* is considered the best representation of the vessel of the future considering length, width, and draft. Dimensions of the *Susan* or "S" Class Maersk are: 1,138 ft long, 140.4 ft wide, 47.6 ft design draft. A photo is shown below in Figure 6.1-1.

**Figure 6.1-1: The *Susan Maersk***



### 6.2 DESIGN CRITERIA & SPECIAL CONSIDERATIONS

A preliminary channel layout for a 48 ft project depth channel was developed by Savannah District based on EM 1110-2-1613, *Hydraulic Design Guidance for Deep-Draft Navigation Projects*. This guidance states that "the design channel width for navigation projects with maximum currents greater than 3.0 knots should be developed with the assistance of a ship simulator design study". Savannah Harbor routinely experiences currents greater than 3.0 knots. Paragraph 7c of ER 1110-2-1403, *Studies by Coastal, Hydraulic, and Hydrologic Facilities and Others*, 1 January 1998 states that "Hydraulic design studies associated with the planning, design, construction, operation, and

maintenance of navigation channels will include a ship or tow simulation investigation unless omission of such an investigation is approved by HQUSACE". Ship simulation was conducted by ERDC for the SHEP and details are documented in the reports titled: 1) *Navigation Study for Savannah Harbor Channel Improvements 2004* 2) *Savannah Harbor Simulations Study 2009* 3) *Savannah Harbor Entrance Channel Simulations 2010 Report* 4) *Vertical Ship Motion Study for Savannah, GA Entrance Channel 2011*. These documents are included in the Engineering Investigations Supplemental Materials and the results of these four studies are discussed in detail in the following sections.

### 6.2.1 Discussions with the Harbor Pilots

The existing navigational channel is not presently designed for two-way traffic for all vessels using the project. However, the harbor pilots indicated that they have instituted their own system of traffic control that allows them to have two-way traffic in certain reaches. The traffic control system generally consists of the pilots onboard any vessel underway being in constant contact with pilots on the other moving vessels. This permits the pilots to adjust the speed of the vessel and time meetings when the vessels are in reaches where the currents, channel banks, and/or other moored vessels do not affect the handling of the vessels under way.

According to the pilots, deep draft vessels avoid meeting in the City Front Channel (approximately Stations 80+000 to 70+000) and in the Bight Channel (approximately Stations 55+000 to 40+000). These are areas where ships are aligning to transit under the Talmadge Bridge or tidal currents affect ship handling. It should be noted that Kings Island Turning Basin (Stations 101+298 to 97+750) is the only place the deepest draft vessels can turn around in the harbor.

The harbor pilots also indicated that they prefer 4 ft of underkeel clearance to move a vessel. Vessels drafting more than 38 ft wait for adequate tide stage to provide the desired underkeel clearance. See Section 6.2.2 for additional discussion of underkeel clearance.

The harbor pilots indicated there are reaches in the channel where they have difficulty maneuvering deep draft vessels. One area is the bend in the vicinity of Station 36+000. They indicated that the currents on the outside of this bend affect vessels on the inbound transit and additional width would help them navigate through this reach. In addition, the reach between Stations 72+000 and 59+000 is difficult to navigate on the north side during certain stages of the tide, and additional width through this turn would be beneficial.

The docking pilots have expressed concern over the size and depths in the existing turning basins other than the Kings Island Turning Basin. However, the proposed design vessel will not be calling at terminal facilities which use these turning basins, and it was determined that they would not be included in this study. Another concern of the docking pilots is the width of the Kings Island Turning Basin. They felt that the basin should be wider to accommodate turning the expansion project's design vessel when other vessels are moored across the river at Container Berths (CB) 1 and 2 which are located directly in front of the turning basin. The docking pilots also expressed concern that turning a vessel moored at CB 7 and 8 would be difficult. They are located immediately upstream of the Kings Island Turning Basin, and vessels will have to be backed one way between the basin and the berth. This comment was considered in the modification of the turning basin design that was submitted and approved as part of the ship simulation study.



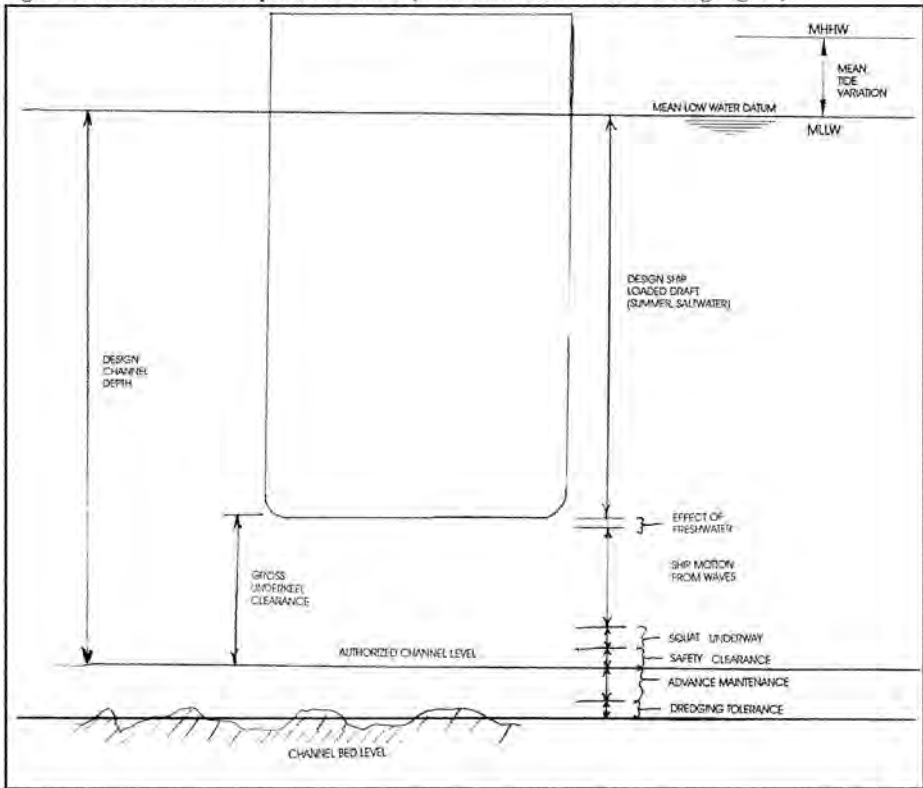
### 6.2.2 Underkeel Clearance

Underkeel clearance is the distance between the bottom of the vessel and the channel bottom required for safe maneuvering of the vessel during transits in the channel and harbor (See **Figure 6.2.2-1**). Gross underkeel clearance (UKC) is the distance under the ship after subtracting the design ship loaded draft from the design channel depth while the ship is in a static condition (such as moored at the dock). The UKC is composed of several ship-related factors including (a) the effect of fresh water, (b) ship motions from waves, (c) squat underway, and (d) safety clearance or net underkeel clearance. The net underkeel clearance (net UKC) is what is left after subtracting the first three components from the UKC.

The following references were used in the evaluation of Underkeel Clearance for SHEP:

- Port of Savannah Minimum Underkeel Clearance Guidelines* (November 1996)
- Port of Savannah Industry Guidelines for Minimum Underkeel Clearances* (Revised February 2009)
- EM 1110-2-1100, *Coastal Engineering Manual, Part V, Coastal Project Planning and Design*
- Savannah Harbor Deepening Georgia and South Carolina Design Memorandum* (October 1992)
- ERDC/CHL CHETN-I-72, *Ship Squat Predictions for Ship Tow Simulator* (August 2006)
- 33 CFR 157.455, *Minimum Underkeel Clearance*
- EM 1110-2-1613, *Hydraulic Design of Deep-Draft Navigation Projects* (May 2006)

**Figure 6.2.2-1: Channel Depth Allowances (Definitions Outlined Following Figure)**

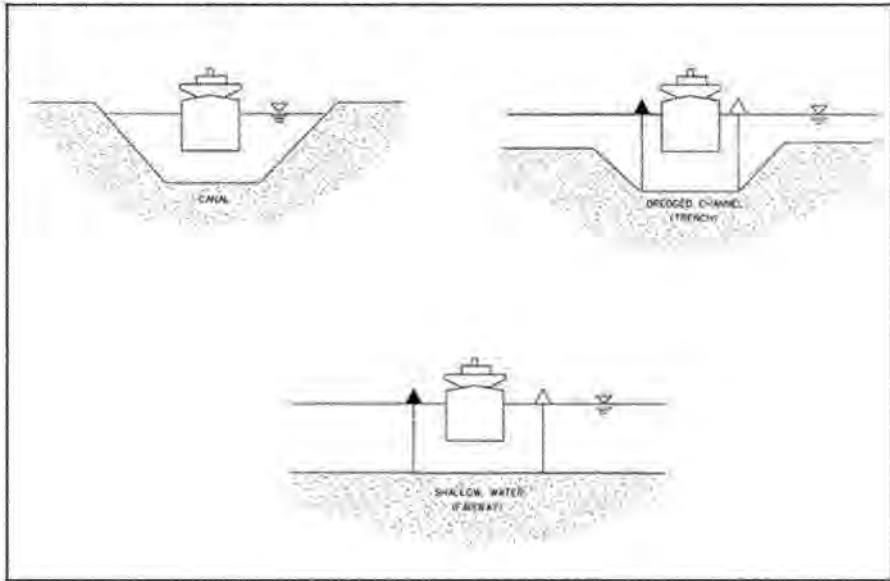


**Effect of Fresh Water** – Savannah Harbor is dominated by salt water; therefore, the effect of fresh water is not significant. Savannah Harbor Pilots Association determines their required underkeel clearance using formulas that are based on a freshwater interface, which yields conservative values for underkeel clearance.

**Ship Motion from Waves** – Vessel vertical motion in response to waves must be considered in design of channel depth at exposed locations. These vertical motions are composed of heave, pitch, and roll. They are functions of ship loading, draft, speed, and handling characteristics; channel depth and cross-section; and wave parameters including period, height, and relative wave direction. Entrance channel design depth is typically greater than interior harbor channel depth because of the need to accommodate wave-induced vertical vessel motions. The accepted practice along the Atlantic coast is to design an entrance channel deeper than an inner harbor channel. A vertical motion study was conducted for the Savannah Harbor Expansion Project which confirmed that the entrance channel depth should be 2 ft deeper than the inner harbor project depth.

**Squat Underway** – Squat is the reduction in underkeel clearance between a vessel at-rest and underway due to the increased flow of water past the moving body. This amount of clearance is primarily dependent on ship characteristics and channel configurations. The main ship parameters include ship draft, hull shape, and ship speed. On average, the Savannah Harbor Navigation Channel can be considered a trench channel. A trench channel is defined as a deepened passage with submerged overbanks on either side as opposed to a canal which has an enclosed cross section with exposed land adjacent to both sides of the channel or a fairway which is a passage with no lateral constraints. See **Figure 6.2.2-2**.

**Figure 6.2.2-2: Navigation Channel Types**



**Safety Clearance or Net UKC** – To protect vessel hull, propellers, and rudders from bottom irregularities and debris, a channel depth allowance for safety is included. A larger clearance (minimum 3 ft) is needed where the channel bottom is hard (such as rock, consolidated sand, or clay) compared to a lesser clearance (2 ft) where the channel bottom is soft. The safety clearance for the SHEP would be considered 2 ft because of the mostly soft channel bottom and absence of rock. Port designers have historically relied on deterministic approaches with large safety factors for channel design. Risk-based models are now recommended to define a useful lifetime with an acceptable level of risk of accidents or groundings. In a risk-based or probabilistic design such as used in this study, a net UKC does not have to be separately included since the clearance has been provided implicitly in the inclusion of predicted ship motions.

**Vessel Speed** – Squat and vertical ship motions are dependent upon ship speed. Ship speed, in turn, is dependent upon several factors including climate conditions, direction and strength of the tide, and the

physical characteristics, including handling, of the vessel itself. Vessel speeds for container vessels can vary from as much as 14 knots in clear areas to as little as 4.5 knots in congested areas or while “meeting” another vessel. Design ship speeds are 8 kt for the Inner Bar Channel and 10 kt for the Outer Bar or Entrance Channel.

### 6.2.2.1 Squat & Underkeel Clearance

To determine the required underkeel clearance, values for squat were calculated for various vessel speeds for the project using the design vessel *Susan Maersk*. The Inner Channel was assumed to have a restricted trench type cross-section with a depth of 47 ft plus 3 ft tidal advantage, width of 500 ft (average), average trench height (measured from the bottom) of 20 ft, and side slopes of 3 (run/rise). The Entrance Channel was assumed to have an unrestricted or open cross-section with a depth of 49 ft plus 3 ft tidal advantage, and width of 600 ft (average). Seven different squat predictors including Ankudinov, Barrass, BNT (Beck, Newman, and Tuck), Eryuzlu, Huuska, Römisch, Yoshimura, were averaged and are listed below (See **Table 6.2.2.1-1**). The BNT squat predictor is used in ERDC’s CADET (Channel Analysis and Design Evaluation Tool).

**Table 6.2.2.1-1: Vessel Speeds and Squat Along Inner Harbor and Entrance Channels**

| Vessel Speed<br>(knots) | Inner Harbor Squat(ft)<br>Restricted** | Outer Bar Squat(ft)<br>Unrestricted** |
|-------------------------|----------------------------------------|---------------------------------------|
| 6                       | 0.9                                    | 0.6                                   |
| 8                       | 1.6                                    | 1.1                                   |
| 10                      | 2.5                                    | 1.7                                   |
| 12                      | 3.7                                    | 2.5                                   |
| 14                      | 5.4                                    | 3.5                                   |
| 16                      | 8.0                                    | 4.7                                   |

\*\*Unrestricted refers to a fairway or open channel whereas restricted refers to a trench channel.

Using the values for squat provided by ERDC for the *Susan Maersk*, **Table 6.2.2.1-1** was used to develop underkeel clearance values for the ship speeds which are listed in **Table 6.2.2.1-2** for the inner harbor and outer entrance channels. The first four rows list the design ship draft, limiting ship speed, project depth, and depth with +3 ft tide for both channels. The next set of three lines shows the excess or additional clearance that is available in a deterministic sense based on the difference between the UKC and the required safety clearance. In this case, there is actually 0.5 ft additional clearance for both channels. The last set of lines shows the similar calculation for the net UKC in a probabilistic sense using the predicted ship squat and vertical motions from the CADET risk-based study. The resulting net UKC is sufficient from this standpoint as well.

Another consideration is the tidal window available for the transits. Both Inner and Outer Channels will require approximately 2 hr for the transit through the channel. Thus, a total of 4 hr is required for transit through both channels. The minimum required tide increase of +3 ft tide has durations of 6 hr for 360 days a year. Pilots will schedule inbound and outbound transits so that they sail with the tide so that the currents are working for them instead of counter flow. Faster ship speeds can be accommodated if the pilots have higher tide levels during the transit. The tradeoff is that the durations of these higher levels will be fewer days per year, but less transit time will be required. In summary,

since the fully-loaded Susan Maersk will not be calling every day of every year, there will be more than sufficient numbers of days with 4+ hr durations to satisfy their requirements.

**Table 6.2.2.1-2: Underkeel Clearance Along Inner Harbor and Entrance Channels**

| Description                                               | Units | Inner Harbor Channel | Outer Entrance Channel |
|-----------------------------------------------------------|-------|----------------------|------------------------|
| Design ship draft                                         | ft    | 47.5                 | 47.5                   |
| Limiting ship speed                                       | kt    | 8.0                  | 10.0                   |
| Project depth                                             | ft    | 47.0                 | 49.0                   |
| Depth with +3 ft tide                                     | ft    | 50.0                 | 52.0                   |
| Underkeel Clearance Calculations – Deterministic Method 1 |       |                      |                        |
| Gross Underkeel Clearance                                 | ft    | 2.5                  | 4.5                    |
| Required Safety Clearance                                 | ft    | 2.0                  | 4.0                    |
| Excess or additional UKC                                  | ft    | 0.5                  | 0.5                    |
| Underkeel Clearance Calculations – Probabilistic Method 2 |       |                      |                        |
| Ship squat                                                | ft    | 1.6                  | 1.7                    |
| Average vertical ship motions                             | ft    | 0.0                  | 1.1                    |
| Sum of squat + ship motions                               | ft    | 1.6                  | 2.8                    |
| Net Underkeel Clearance                                   | ft    | 0.9                  | 1.7                    |

Thus, it can be concluded that vessels with a 47.5 ft draft can safely transit the inner harbor at 8 knots and the entrance channel at 10 knots. A minimum depth of 50 ft (+3 ft tide) in the Inner Harbor Channel and 52 ft (+3 ft tide) in the Entrance Channel is required for safe transits for the fully-loaded, 47.5-ft-draft *Susan Maersk*. Faster ship speeds are possible if higher tide levels are used, but the available durations are reduced such that a transit may not be possible every day of the year. This is an example of the factors that are used to determine underkeel clearance. More detailed analysis is contained in Section 6.3.4.4 which discusses the ERDC vertical motion study.

#### 6.2.2.2 Existing Policy, Port of Savannah

Port of Savannah Minimum Underkeel Clearance Guidelines were discussed in October 1996 by a “Port Users Workgroup” composed of representatives of the Port of Savannah and Port of Brunswick and adopted November 27, 1996. Guidelines were established to proactively prevent maritime accidents and casualties as well as removing ambiguity and inconsistency in procedures necessary to reduce the likelihood of vessels over 1600 gross tons grounding during transit or while at an assigned berth within the Port of Savannah. The following guidelines were adopted for all conditions of tide and weather:

- 4 feet for transits in the navigation channel between the sea buoy, across the Entrance Channel, through Jones Island Range, Station -14+000, where the project depth of the channel decreases by 2 feet.

- 2 feet for transits between Jones Island Range and the point in the navigation channel which is adjacent to the facility of destination.

These are minimum guidelines and are not intended to be limiting for pilots, operators, or owners that choose to require a higher degree of safety for their operations to ensure a vessel's safe transit and mooring. These guidelines are to be reviewed bi-annually by the signatory body to address any necessary changes and ensure all parties are following guidelines as agreed upon. The most recent update confirming these guidelines was published in February 2009 in the *Port of Savannah Industry Guidelines for Minimum Underkeel Clearances*. Additionally, this guidance does not amend or supersede applicable underkeel clearance requirements for single bottom tank ships and barges detailed in 33 CFR 157.455.

An interview conducted with the Master Pilot revealed that current pilot regulations require a minimum underkeel clearance of 4 feet, and a pilot will usually wait to take advantage of the tide (tidal lift) if it appears 4 feet will not be available during the entire transit of a vessel. Past practice has shown that pilots move vessels when they have 4 feet of underkeel clearance. This requires that some vessels wait at the docks or the sea buoy until adequate depth can be gained from tidal fluctuation. Since Savannah Harbor experiences an average tidal range of 7 to 8 feet, it is a common practice for the pilots to use the tides to advantage in loading and transit of deep draft ships.

### 6.2.3 Pipeline Impacts

To avoid damaging any existing utilities which cross the navigation channel, it was necessary to determine a) the location, both horizontal and vertical, of the utilities and b) the amount of overburden required to provide an adequate factor of safety for the pipelines after deepening of the channel. Consideration was also given to future maintenance of the channel in the pipeline areas.

Pipeline industry standards for clearance guidance stated that 4 ft of cover was required in areas of new pipeline placement ( Pipeline and Hazardous Materials Safety Administration, DOT Rules and Regulations, section 192.327 Cover, paragraph (e)... "**all pipe installed in a navigable river, stream, or harbor must be installed with a minimum cover of 48 inches**"). The Engineering Research and Design Center (ERDC) Dredging Operations Technical Support (DOTS) program was also contacted to request the US Army Corps of Engineers (USACE) policy regarding dredging over pipelines. ERDC confirmed that no standard exists. Documentation of the DOTS assistance titled, *Dredge Vertical Construction Accuracy*, is included in the Engineering Investigations Supplemental Materials.

#### 6.2.3.1 Pipeline Locations

All available District permits applicable to river crossings in the project area were collected. This effort helped to determine which areas had potential conflict with the harbor deepening based on as-built drawings on file with regulatory permits. In addition, a response was solicited from industries and property owners adjacent to the navigation channel by public notice in April 2007, informing them of the USACE's intention to study the proposed deepening of the harbor and inquiring to gather information on any existing or proposed utility crossings. The results of the investigation are as follows:

- It was determined that Georgia Power crossings are all overhead lines and the former “in-channel” crossings discovered by research of district permit applications no longer exist.
- It was determined that all underground utility crossings to Hutchinson Island at approximate Stations 68+000, 72+000, and 78+000 would not conflict with the proposed deepened channel based on drawings received from Hussey, Gay, Bell & DeYoung. The depths of these lines were 31 ft, 33 ft, and 23 ft respectively below the proposed channel bottom alleviating any concern for their safety.
- Areas of potential conflict included the Southern Natural Gas (SNG) pipelines at Harbor Station 51+500 (4.5 ft clearance based on 1977 as-built drawings) and the International Paper (IP) pipeline at Harbor Station 89+250 (8 ft clearance). (Note: the amount of clearance is based on the difference between the elevation of the pipeline and the maximum dredging depth of 15 ft below the existing 42 ft project depth which includes 6 ft deepening, advance maintenance (varies from 2 ft to 4 ft based on reach of channel), 2 ft allowable over-depth, and 3 ft dredging disturbance.

The USACE met with local officials from SNG to present its concerns. In February 2008, the USACE received results from SNG of the survey of their pipeline crossing done by T. Baker Smith in October 2007. After correspondence with T. Baker Smith in which accurate proposed channel location coordinates were provided and the difference in vertical datum was resolved, it was determined that there is between 11 ft to 12.5 ft of clearance between the maximum proposed disturbed channel depth and the top of the easternmost pipeline. Survey results from the westernmost line were received in May 2009. The West line appears to be 3 feet above the East line at the closest point to the proposed channel excavation at -68 ft MLLW. SNG officials believe this will still be acceptable as long as they are able to coordinate closely with USACE and the dredging contractor.

The USACE also contacted International Paper’s (IP) point of contact to advise them of plans for deepening the harbor. IP provided an electronic file showing a cross section of their pipeline. The USACE provided the design template for the deepened channel including disturbance depth on the cross section. All data received to date, indicates that the IP pipeline will retain 8 ft of cover in addition to 3 ft allowed for dredging disturbance on the Northern side of the channel after Deepening.

### 6.2.3.2 Dredging Methodologies in Areas of Pipeline Crossing

The Savannah District solicited input from the Mobile District as well as the dredging industry input to determine their level of accuracy in dredging over pipelines. Input from Industry and USACE Districts is summarized in the following paragraphs.

**Industry Input** – Conversation with Norfolk Dredging revealed that the company routinely dredges within 3 – 4 ft horizontal distance away from pipelines in Philadelphia District (Schuylkill River – 400 ft wide cut). The pipelines locations are well documented and the dredging firm takes precautions, (i.e., swing slow, cut off cutter-head over line, etc.). The dredge operator can tell when he is dredging over previously dredged material. This issue was also discussed with Great Lakes Dredge and Dock, Inc. They stated from experience, the dredge can remove material within 5 ft vertical distance of a pipeline based on the distance between the over-depth prism and top of pipe. They also stated that if the dredge operator was not absolutely sure of the pipeline location he could also use the mechanical dredge to come within 25 ft of either side of the pipeline to remove material and recommended using suction without the cutterhead turning if material is soft over the pipeline.



New Orleans District Input –New Orleans District has a great deal of experience in dredging over pipelines having administered over a hundred contracts dealing with this issue in Mobile, Galveston, New Orleans, Vicksburg, and Philadelphia. They provided specifications listing necessary precautions involving dredging over pipelines and stressed the need to insure correct calibration of cutterhead positioning. They did express concern that we have to deal with greater tidal exchange than what they normally deal with on the Gulf coast. This fact complicates tidal height calculations in Savannah Harbor. New Orleans District also stated that regarding dredging over pipelines, dredging is usually limited to 10 ft below project grade or 8 ft below required depth with 2 ft for advance maintenance and allowing 1 ft for over-depth. This equates to a 7 ft dredging tolerance over pipelines. They agreed with the tolerance of 8 ft being used for Savannah which includes 3 ft dredging disturbance as part of the tolerance.

Savannah District Input – Engineering Division initially recommended dredging up to but not over the SNG pipeline and allowing river currents to remove remaining new work dredged materials. The same practice would apply to O&M dredging operations. Velocities were examined in vicinity of the SNG pipelines to determine if this approach was feasible as this is the current practice adjacent to Old Fort Jackson. Even though current velocities in the Old Fort Jackson reach are influenced by ebb tides coming out of the Back River, the current velocities near the SNG facility are similar.

Detailed investigations determined the velocities to be comparable in front of Old Fort Jackson (maximum bottom 1.4 – 1.8 fps, maximum surface 3.7 – 4.2 fps) and over the SNG pipeline (maximum bottom 1.4 – 1.8 fps, maximum surface 3.7 – 4.5 fps). Maximum velocities over the International Paper pipeline were somewhat smaller (maximum bottom 1.6 fps, maximum surface 3.4 fps). These measurements suggested that it may be possible to provide adequate depth over the SNG pipeline by dredging on either side of the pipeline and allowing the currents remove maintenance material similar to how the area in front of Old Fort Jackson is maintained.

However, additional research revealed that although the reach in front of Old Fort Jackson is not currently dredged as part of the maintenance contract, it was initially deepened to 44 ft by a cutterhead dredge. Dredge scars in the Miocene layer of clay are still visible in the Miocene material in photos taken by side scan sonar. Since these cuts are still evident and have not been “smoothed out” by currents, it is unwise to assume that currents are swift enough to remove deepening, new work materials. The clays of the Miocene layer are too stiff to be removed by anything other than mechanical equipment. The clays reside at elevation -45 ft to -47 ft MLLW in front of Old Fort Jackson and from -43 ft to -46 ft MLLW in the SNG pipeline area, and around -44 ft MLLW at the International Paper pipeline.

### 6.2.3.3 Mitigation During Construction

Based on the proximity to the pipelines, the USACE would specify the following constraints during construction dredging:

- Signs and ranges would indicate “no dredge” areas in the field and would be indicated on the drawings as well during construction and operations and maintenance (O&M) dredging.
- SNG would be contacted in advance of dredging to shut off flow of gas into pipeline.



- Cutterhead rotation would be suspended within 25 ft of the pipelines and an attempt would be made to remove material using only suction from the dredge pump. If material is too difficult to remove over pipeline, the contractor may be required to incorporate clamshell operations to more safely remove material.

#### 6.2.3.4 Conclusion/Recommendation

The process of dredging in the SNG and LP pipeline areas will follow the accepted practice of approaching utility crossings from both upstream and downstream without “spudding” or dredging directly over the pipelines. The Savannah District will specify strict adherence to these procedures and will specify that its contractors stay within prescribed limits as determined by as-built drawings provided by utility owners.

Engineering Division recommends adopting the current dredging policy in areas of concern by:

- Not “spudding” over the pipelines but allowing dredging over and within the vertical limits established by construction (5 ft for gas pipeline).
- Limiting the amount of advance maintenance in the affected areas to provide necessary clearance if the pipeline location falls within 5 ft of required clearance and use precautions listed above.
- If new work material is unable to be removed by suction without turning the cutterhead, the contractor may have to employ mechanical dredge to initially remove material.

Letters detailing this information were sent to International Paper and Southern Natural Gas on May 5, 2008 and are included in the Engineering Investigations Supplemental Materials.

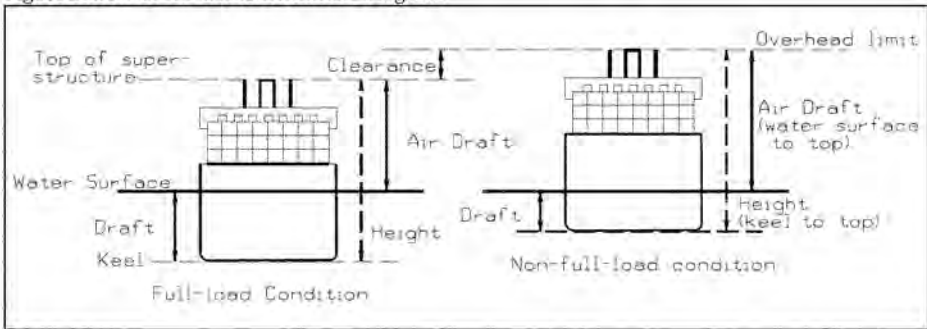
### 6.2.4 Air Draft Analysis

#### 6.2.4.1 Purpose for Analysis

The purpose of the air draft analysis is to confirm that air draft of the design fleet mix for the SHEP does not violate the air draft listed for the air draft at Mean Higher High Water (MHHW) associated with the Talmadge (Savannah River) bridge.

#### 6.2.4.2 Definitions

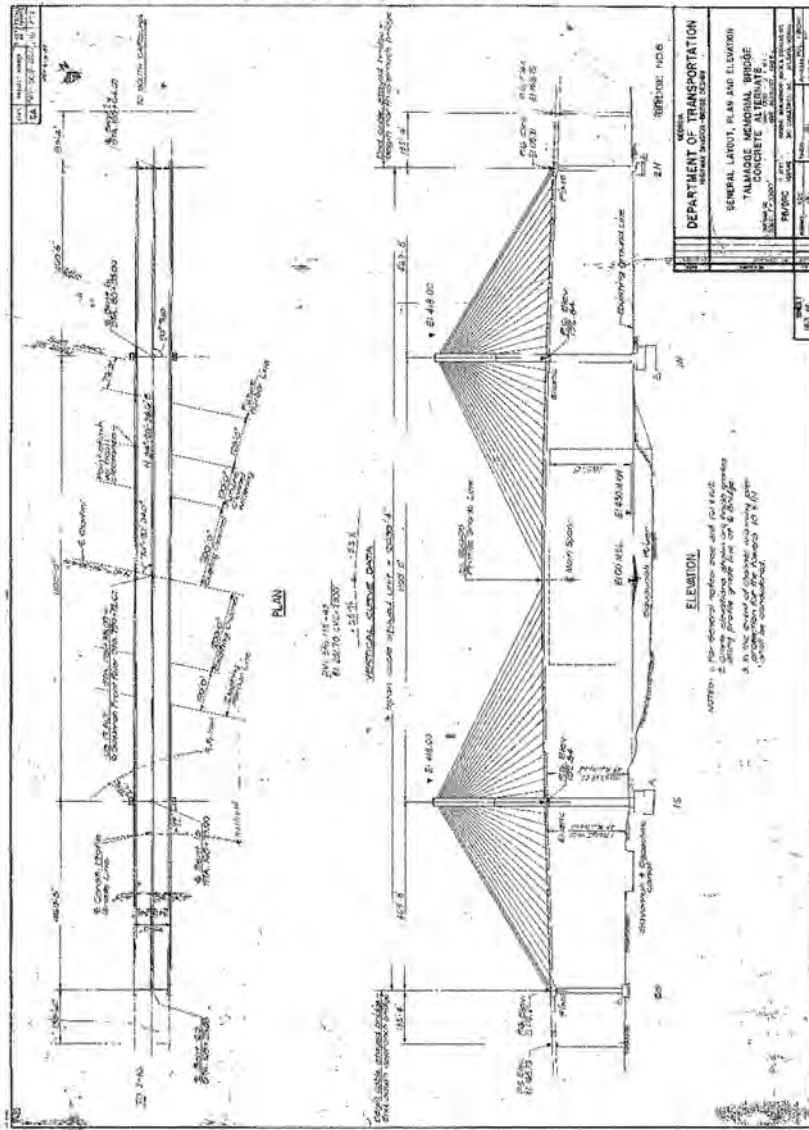
The term “air draft” associated with a vessel is commonly accepted as the distance between the elevation of the water line in which a vessel rests in the water and the top of the superstructure of the vessel. This distance varies based on the draft of the vessel and whether the height of the vessel includes antenna or other superstructure height. Draft can depend on how heavy a vessel is loaded, salinity, water temperature, etc. Many large vessels have antenna or superstructure that can be lowered to decrease air draft. **Figure 6.2.4.2-1** shows the relationship between height (from Keel to Top) versus height, or air draft (from surface of the sea to Top) as well as how air draft varies depending on loading condition.

**Figure 6.2.4.2-1: Air Draft Definition Diagram**

### 6.2.4.3 Bridge Height Restriction

The Talmadge (Savannah River) bridge has an air draft height of 185 ft above MHHW, as per design drawings provided by Georgia DOT. See **Figure 6.2.4.3-1**. This height is based on the lower edges of the span above the navigation channel. Height above MHHW actually ranges from 192 ft to 200 ft in the middle of the span. The 185 ft distance is used by the Savannah Harbor pilots as the official (conservative) air draft of the bridge.

Figure 6.2.4.3-1: Talmadge Bridge Design Drawing



#### 6.2.4.4 Tolerance

The Savannah office for the USCG deferred to the Savannah River Harbor Pilots Association for restrictions on air draft. The Savannah River Harbor Pilots Association stated that there was no official policy regarding the air draft of vessels coming into the harbor. From information gained, a vessel's air draft is provided to the pilot and the Coast Guard before the vessel enters the channel. One carrier interviewed stated they use 3 ft as minimum allowance.

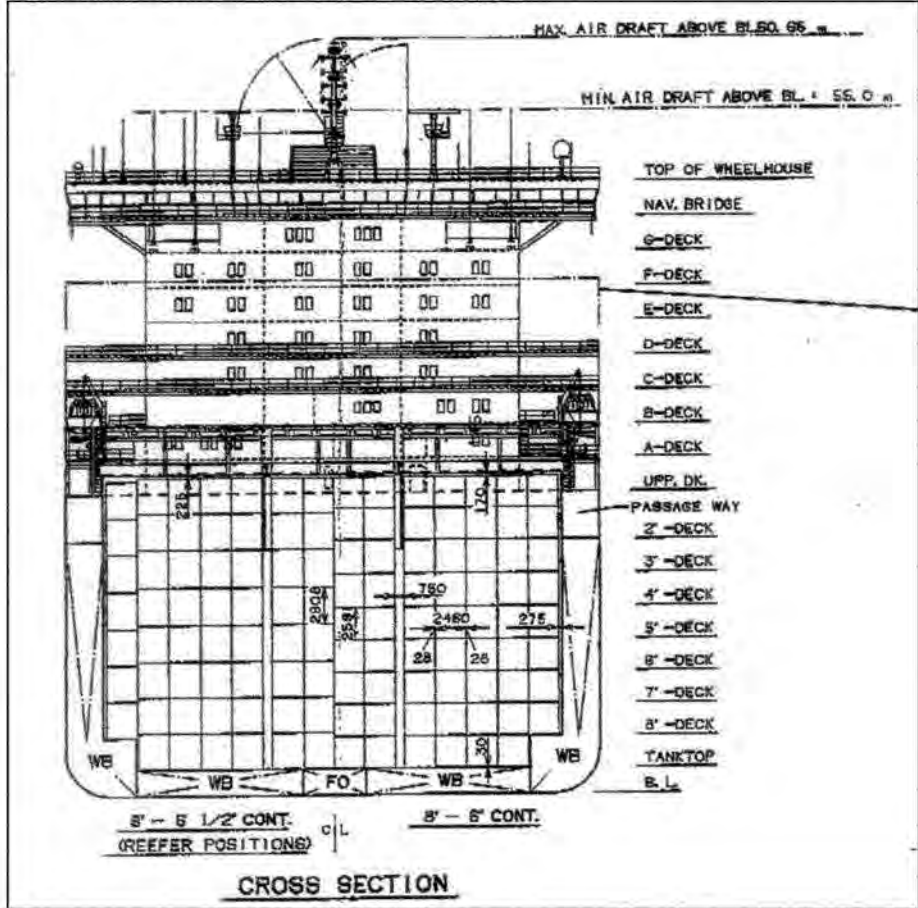
#### 6.2.4.5 Design Vessel Specifications

Research consultation with Maersk Lines provided information for the design vessel *Susan Maersk* regarding air draft. Apparently, the term "air draft" is also used to refer to the height of a vessel from the BL (which can refer to base line or bilge line) to the top of the superstructure. The height for the *Susan Maersk* is defined as 55 meters (180.4 ft) with antenna down, minimum height. The maximum height is 60.65 meters (199.0 ft), antenna up. The Maersk Lines representative stated that the antenna is not removed to reach the minimum height but tilted back. This is part of a routine check list but is only required in a few ports to meet air draft requirement. The draft of the *Susan Maersk* ranges from the design draft of 47.6 ft to a minimum of 29 ft, thus, the air draft would range as follows:

| Max height<br>(Antenna up)   | Draft              | Air Draft  |
|------------------------------|--------------------|------------|
| 199.0 ft                     | - 47.6 ft (design) | = 151.4 ft |
| 199.0 ft                     | - 29 ft (minimum)  | = 170.0 ft |
| Max height<br>(Antenna back) | Draft              | Air Draft  |
| 180.4 ft                     | - 47.6 ft (design) | = 132.8 ft |
| 180.4 ft                     | - 29 ft (minimum)  | = 151.4 ft |

Figure 6.2.4.5-1 shows a schematic of the *Sovereign Maersk* (a “sister” vessel of the *Susan Maersk*) provided by Maersk Lines which substantiates their definition of height being from keel to top of structure.

Figure 6.2.4.5-1: Maersk Air Draft Definition Diagram



#### 6.2.4.6 Design Fleet Mix

Discussions between the District and the USACE Institute for Water Resources (IWR) regarding the design fleet mix are outlined in the following paragraph.

IWR discussed proprietary information with the District listing vessels that were considered to make up the design fleet. The “workhorse” for the projected fleet is expected to be an 8200 (+/- 400) TEU vessel. The upper height limit for these vessels was listed at 62 m (meters) or 157 ft for the design draft of 47.6 ft. Even if the superstructure was raised 10 ft to accommodate another tier of containers and the vessel was light loaded by an additional 10 ft (any more would not be economically considered according to IWR), the air draft would only increase to 177 ft, which is still within an acceptable tolerance considered by the Savannah River Harbor pilots. IWR was comfortable in extending this range up to a 9000 TEU vessel.

#### 6.2.4.7 Conclusion

Neither the design vessel nor the design fleet mix will violate the air draft restriction presented by the Talmadge (Savannah River) Bridge.

### 6.2.5 Berth Design and Dredging

To accommodate the SHEP design vessel, GPA requested that an offset of 160 ft from Container Berths (CB) 2-9 be incorporated into the channel design. To provide the extra berth width, the existing channel either had to be realigned or a portion of the channel had to be abandoned. Realigning the channel in front of the berths would have required considerable real estate acquisition on the north side of the channel. During ship simulation, pilots were able to navigate this reach of channel using a reduced width of channel to accommodate the design berth width but will be restricted to one-way traffic in this reach. Results of the ship simulation for this channel realignment are detailed in the March 31, 2009 memorandum from ERDC titled *Savannah Harbor Simulations Study 2009*, which is included in the Engineering Investigations Supplemental Materials.

GPA has already deepened CB 2-3 and 8-9 to safely dock deeper draft vessels that have come into port using the tidal advantage. CB 4-7 will be deepened at a future time. There are no current plans to deepen CB 1. GPA will be responsible for O&M dredging of the widened berth area. **Table 6.2.5-1** shows the quantities of material that were/are required to provide necessary depths in front of the berths. Plates 01 and 02 in Attachment 1 show the berth design requested by GPA.

**Table 6.2.5-1: GPA Container Berth Material Quantities**

| <b>Berth</b> | <b>Location<br/>Relative to Channel<br/>Centerline Station</b> | <b>42 ft<br/>Depth<br/>(cy)</b> | <b>43 ft<br/>Depth<br/>(cy)</b> | <b>44 ft<br/>Depth<br/>(cy)</b> | <b>45 ft<br/>Depth<br/>(cy)</b> |
|--------------|----------------------------------------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| CB-2         | 95+364 to 96+359                                               | 1,049                           | 2,006                           | 3,876                           | 7,104                           |
| CB-3         | 96+359 to 97+687                                               | 2,046                           | 3,585                           | 6,137                           | 9,537                           |
| CB-4         | 97+687 to 98+362                                               | 947                             | 1,520                           | 2,744                           | 5,207                           |
| CB-5         | 98+362 to 99+352                                               | 3,985                           | 6,059                           | 8,664                           | 11,652                          |
| CB-6         | 99+352 to 100+052                                              | 6,472                           | 11,914                          | 18,038                          | 24,377                          |
| CB-7         | 100+052 to 101+153                                             | 19,011                          | 26,621                          | 35,199                          | 44,814                          |
| CB-8         | 101+153 to 102+326                                             | 1,216                           | 2,468                           | 5,385                           | 11,128                          |
| CB-9         | 102+326 to 103+192                                             | 5,313                           | 9,268                           | 14,288                          | 20,526                          |
| <b>Berth</b> | <b>46 ft<br/>Depth<br/>(cy)</b>                                | <b>47 ft<br/>Depth<br/>(cy)</b> | <b>48 ft<br/>Depth<br/>(cy)</b> | <b>49 ft<br/>Depth<br/>(cy)</b> | <b>50 ft<br/>Depth<br/>(cy)</b> |
| CB-2         | 10,891                                                         | 14,770                          | 18,696*                         | 22,652                          | 26,610                          |
| CB-3         | 13,852                                                         | 18,775                          | 23,940*                         | 29,151                          | 34,634                          |
| CB-4         | 8,765                                                          | 12,824                          | 16,889                          | 20,953                          | 25,017                          |
| CB-5         | 14,801                                                         | 18,022                          | 21,244                          | 24,466                          | 27,689                          |
| CB-6         | 30,829                                                         | 37,488                          | 44,234                          | 51,001                          | 57,771                          |
| CB-7         | 54,990                                                         | 65,350                          | 75,751                          | 86,164                          | 96,582                          |
| CB-8         | 18,486                                                         | 26,074                          | 33,680*                         | 41,287                          | 48,894                          |
| CB-9         | 27,097                                                         | 33,672                          | 40,464*                         | 47,168                          | 53,873                          |

\* Berths already deepened.

## 6.3 PROPOSED CHANNEL DESIGN

### 6.3.1 Design Template

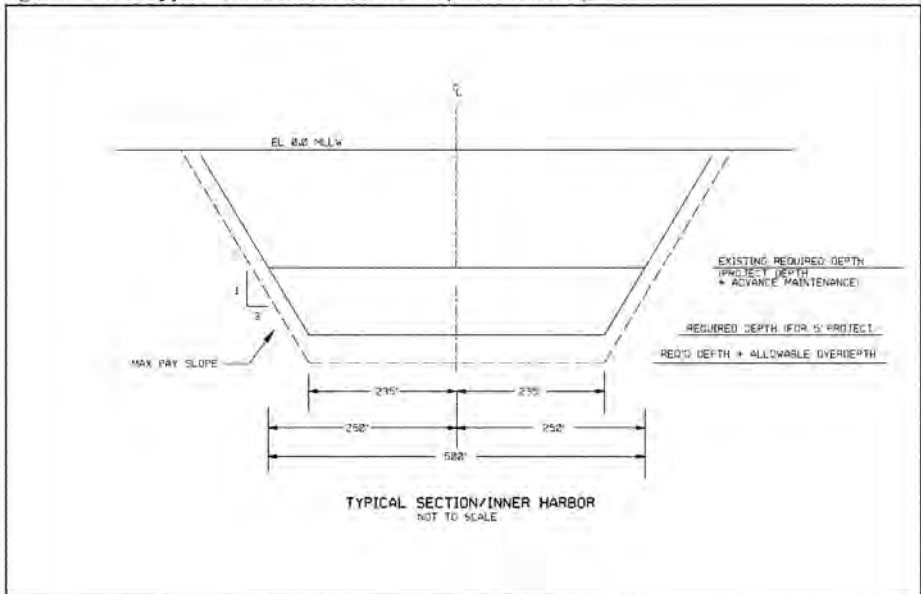
In order to reduce the amount of upland required to expand the channel, it was determined that the inner harbor channel would be deepened on its existing 1V/3H (1 vertical/3 horizontal) side slope. This design decision was made by the members of the project delivery team for the SHEP and was included in the Savannah Harbor Deepening Feasibility Report (Section 203) and Tier I EIS 1998 report and received no negative comments. Prior to adoption, this design was elevated through the vertical team

including the South Atlantic Division office (SAD), USACE Headquarters and ASA (CW). See **Figure 6.3.1-1** and **6.3.1-2** for typical sections for the SHEP inner harbor and entrance channel. **Tables 6.3.1-1** and **6.3.1-2** outline the SHEP alternative project widths and depths.

Previous deepening projects had deepened the channel using the existing widths, requiring additional real estate. By deepening on the existing side slope, the new bottom width would be narrower than the existing width, but no additional real estate would be required except in the areas requiring bend wideners in the channel to accommodate the longer design vessel. The bottom width in the areas not requiring bend wideners is dependent on the design depth. In addition to the minimization of real estate requirements, this design minimizes the amount of dredging required which is a significant cost savings and also minimizes impacts to cultural resources and wetlands along the channel banks. This channel design was used in the ship simulation study and was determined adequate for one-way traffic. Details of the Ship Simulation Study are included in the report titled *Navigation Study for Savannah Harbor Channel Improvements*, Engineering Investigations Supplemental Materials and discussed in Section 6.3.2.

The study analysis resulting in bend wideners, meeting areas, and the channel extension required for inclusion in the project are discussed in detail in the following sections and supporting documents in the supplemental materials. **Figure 6.3.1-3** shows the locations of all of the SHEP navigation features proposed for the project.

**Figure 6.3.1-1: Typical Channel Cross Section (Inner Harbor)**





**Figure 6.3.1-2: Typical Channel Cross Section (Entrance Channel)**

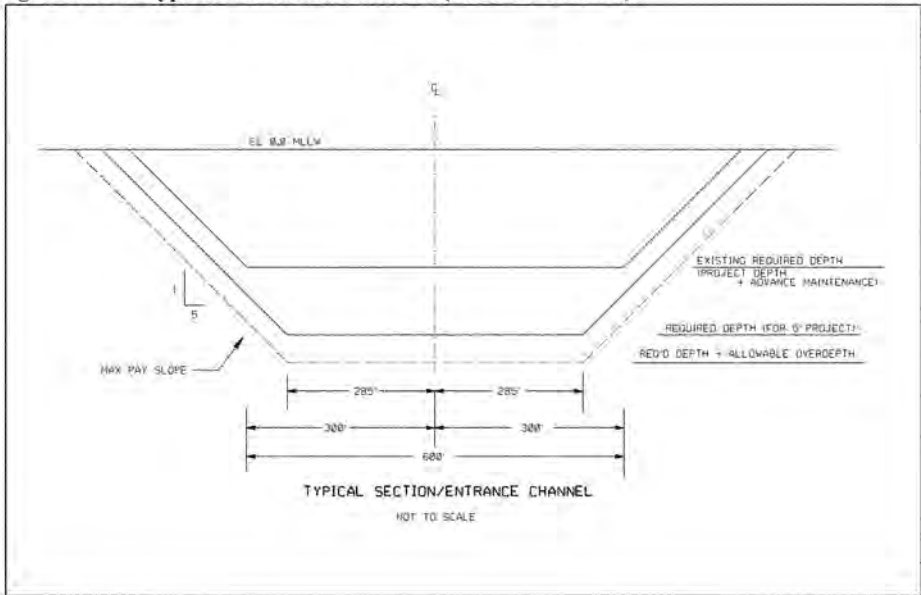


Figure 6.3.1-3: Location of SHEP Navigation Features (Bend Wideners, Meeting Areas and Channel Extension)

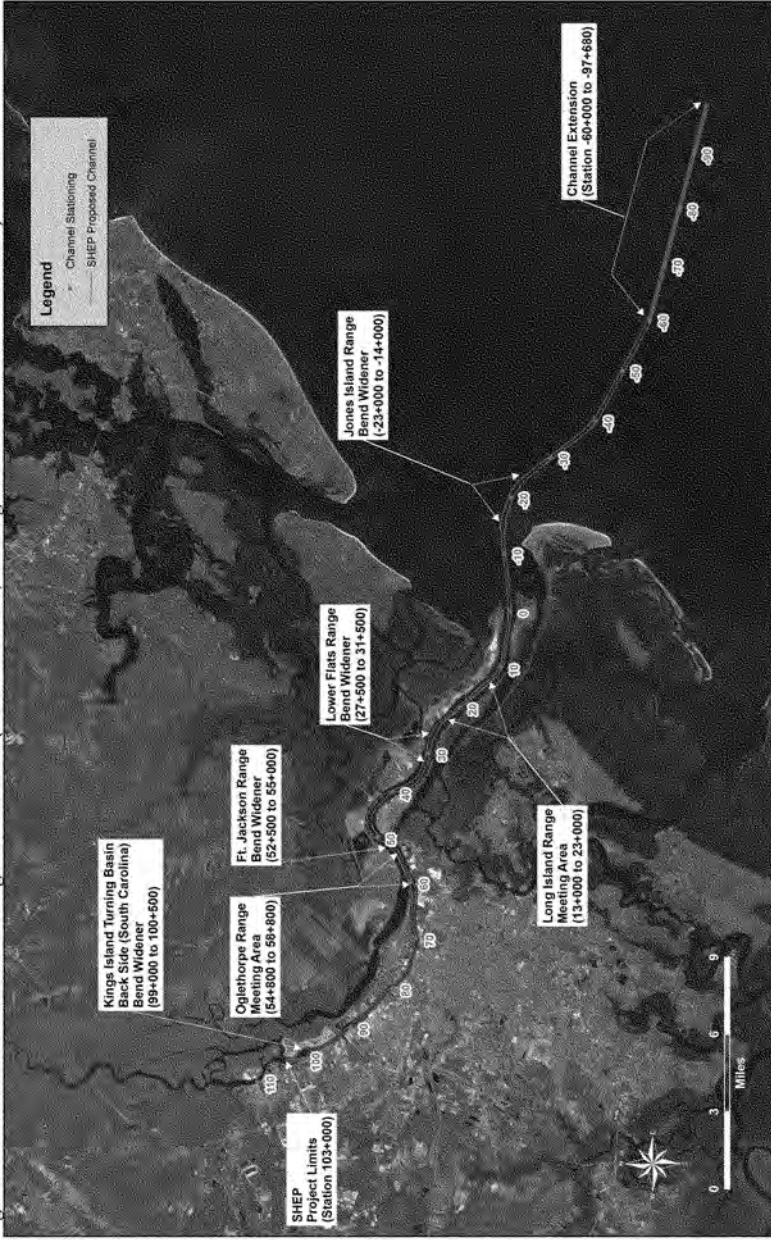


Table 6.3.1-1: Currently Authorized Channel and SHEP Channel Alternative Widths (ft)

| Range Name                                 | Lower Stationing     | Upper Stationing | Currently Authorized Project | 46 ft Project       | 47 ft Project       | 48 ft Project       |
|--------------------------------------------|----------------------|------------------|------------------------------|---------------------|---------------------|---------------------|
| S8                                         | -98+600 <sup>A</sup> | -60+000          | <i>not applicable</i>        | 576                 | 570                 | 564                 |
| Tybee                                      | -60+000 <sup>A</sup> | -40+522          | 600                          | 576                 | 570                 | 564                 |
| 0A                                         | -40+522              | -38+186          | 800                          | 776                 | 770                 | 764                 |
| Bloody Point                               | -38+186              | -23+475          | 600                          | 576                 | 570                 | 564                 |
| 1A                                         | -23+475              | -20+832          | 800                          | 858 <sup>B</sup>    | 858 <sup>B</sup>    | 858 <sup>B</sup>    |
| Jones Island                               | -20+832              | -16+142          | 700                          | 758 <sup>B</sup>    | 758 <sup>B</sup>    | 758 <sup>B</sup>    |
| 2A                                         | -16+142              | -13+771          | 800                          | 864 <sup>B</sup>    | 861 <sup>B</sup>    | 858 <sup>B</sup>    |
| Tybee Knoll Cut                            | -13+771              | -1+380           | 500                          | 476                 | 470                 | 464                 |
| 4                                          | -1+380               | 1+552            | Varies                       | Varies              | Varies              | Varies              |
| New Channel                                | 1+552                | 9+526            | 500                          | 476                 | 470                 | 464                 |
| 6                                          | 9+526                | 11+385           | 600                          | 600                 | 600                 | 600                 |
| Long Island Crossing                       | 11+385               | 24+920           | 500                          | 476                 | 470                 | 464                 |
| <i>Long Isl. Meeting Area<sup>1</sup></i>  | <i>13+000</i>        | <i>23+000</i>    | <i>not applicable</i>        | <i>576</i>          | <i>570</i>          | <i>564</i>          |
| 8                                          | 24+920               | 27+317           | 800                          | 776                 | 770                 | 764                 |
| Lower Flats                                | 27+317               | 31+037           | 600                          | 664 <sup>B</sup>    | 661 <sup>B</sup>    | 658 <sup>B</sup>    |
| 10 through 12                              | 31+037               | 36+948           | 600 to 700                   | 600 to 700          | 600 to 700          | 600 to 700          |
| Upper Flats                                | 36+948               | 40+437           | 550                          | 538                 | 535                 | 532                 |
| 14                                         | 40+437               | 41+693           | 500 to 700                   | 488 to 688          | 485 to 685          | 482 to 682          |
| Bight Channel                              | 41+693               | 49+489           | 700                          | 700                 | 700                 | 700                 |
| Ft. Jackson Channel                        | 49+489               | 53+127           | Varies                       | Varies <sup>C</sup> | Varies <sup>C</sup> | Varies <sup>C</sup> |
| 21                                         | 53+127               | 54+481           | 600                          | 664 <sup>B</sup>    | 661 <sup>B</sup>    | 658 <sup>B</sup>    |
| Oglethorpe                                 | 54+481               | 61+405           | 500                          | 488                 | 485                 | 482                 |
| <i>Oglethorpe Meeting Area<sup>2</sup></i> | <i>54+800</i>        | <i>60+680</i>    | <i>not applicable</i>        | <i>588</i>          | <i>585</i>          | <i>582</i>          |
| 23                                         | 61+405               | 63+277           | Varies                       | Varies              | Varies              | Varies              |
| 24 through 25                              | 63+277               | 69+734           | 500                          | 470                 | 467                 | 464                 |
| 26                                         | 69+734               | 71+128           | 600                          | 588                 | 585                 | 582                 |
| City Front Channel                         | 71+128               | 76+537           | 500                          | 476                 | 470                 | 464                 |
| 28                                         | 76+537               | 77+283           | 550                          | 538                 | 535                 | 532                 |
| Marsh Island Channel                       | 77+283               | 87+642           | 500                          | 476                 | 470                 | 464                 |
| 32                                         | 87+642               | 90+701           | Varies                       | Varies              | Varies              | Varies              |
| 33                                         | 90+701               | 93+933           | 500                          | 476                 | 470                 | 464                 |
| 34                                         | 93+933               | 95+378           | 500                          | 449                 | 446                 | 443                 |
| 35                                         | 95+378               | 97+543           | 500                          | 437                 | 434                 | 431                 |
| Kings Isl. Turning Basin                   | 97+543               | 103+000          | Varies                       | Varies <sup>B</sup> | Varies <sup>B</sup> | Varies <sup>B</sup> |

Notes:

<sup>1</sup> Includes 2,000-foot transition, <sup>2</sup> Includes 1900-foot transition<sup>A</sup> Existing project starts at -60+000, the 47 ft project would require 37,680 linear ft of channel extension to -97+680<sup>B</sup> Width expansion on north side of channel only<sup>C</sup> Width expansion on south side of channel only

**Table 6.3.1-2: Existing and Alternative Project Channel Depths (ft MLLW)**

| Stations                   | Currently Authorized Navigation Channel |                     |                              | SHEP Alternative Project Depths* |                     |                     |                     |                     |
|----------------------------|-----------------------------------------|---------------------|------------------------------|----------------------------------|---------------------|---------------------|---------------------|---------------------|
|                            | Authorized Project Depth                | Advance Maintenance | Maintenance Dredging Depth** | 44 ft Project Depth              | 45 ft Project Depth | 46 ft Project Depth | 47 ft Project Depth | 48 ft Project Depth |
| -98+600 to -60+000**       | n/a                                     | n/a                 | n/a                          | 48                               | 49                  | 50                  | 51                  | 52                  |
| -60+000 to -14+000         | 44                                      | 0                   | 46                           | 48                               | 49                  | 50                  | 51                  | 52                  |
| -14+000 to 0+000           | 42                                      | 2                   | 46                           | 48                               | 49                  | 50                  | 51                  | 52                  |
| 0 to 24+000                | 42                                      | 2                   | 46                           | 48                               | 49                  | 50                  | 51                  | 52                  |
| 24+000 to 35+000           | 42                                      | 4                   | 48                           | 50                               | 51                  | 52                  | 53                  | 54                  |
| 35+000 to 37+000           | 42                                      | 6                   | 50                           | 52                               | 53                  | 54                  | 55                  | 56                  |
| 37+000 to 50+500           | 42                                      | 4                   | 48                           | 50                               | 51                  | 52                  | 53                  | 54                  |
| 50+500 to 52+750           | 42                                      | 4                   | 48                           | 50                               | 51                  | 52                  | 53                  | 54                  |
| 52+750 to 54+000           | 42                                      | 4                   | 48                           | 50                               | 51                  | 52                  | 53                  | 54                  |
| 54+000 to 60+250           | 42                                      | 4                   | 48                           | 50                               | 51                  | 52                  | 53                  | 54                  |
| 60+250 to 66+750           | 42                                      | 4                   | 48                           | 50                               | 51                  | 52                  | 53                  | 54                  |
| 66+750 to 70+000           | 42                                      | 4                   | 48                           | 50                               | 51                  | 52                  | 53                  | 54                  |
| 70+000 to 102+000          | 42                                      | 2                   | 46                           | 48                               | 49                  | 50                  | 51                  | 52                  |
| 102+000 to 103+000         | 42                                      | 0                   | 44                           | 46                               | 47                  | 48                  | 49                  | 50                  |
| Kings Island Turning Basin | 42                                      | 8                   | 52                           | 54                               | 55                  | 56                  | 57                  | 58                  |

\*Alternative Project Depths include Currently Authorized Advance Maintenance and Over-depth.

\*\* Stations -98+600 to -60+000 are not currently part of the Federal Project, the SHEP Alternative Project Depths require that the navigation channel be extended across the ocean bar.

Station -98+600 is the extended channel station associated with the 48 ft project depth. The 47 ft project depth extends to station -97+680.

\*\*\*Maintenance Dredging includes 2 ft of Over-depth.

### 6.3.2 Ship Simulation

A navigation study utilizing real-time ship simulation to evaluate the proposed improvements to Savannah Harbor was conducted by ERDC for the SHEP. Details are documented in the reports titled: 1) *Navigation Study for Savannah Harbor Channel Improvements* 2) *Savannah Harbor Simulations Study 2009* 3) *Savannah Harbor Entrance Channel Simulations 2010 Report* 4) *Vertical Ship Motion Study for Savannah, GA Entrance Channel*. These documents are included in the Engineering Investigations Supplemental Materials. The results of the first two studies are discussed in detail in the following sections. The results of the third and fourth studies are discussed in the next section.

Two design ships were used for the study: one to represent existing vessel traffic and the other to represent future traffic. The design ship for the currently authorized channel was the *SL Performance*, a Panamax containership loaded to 33 ft. The *SL Performance* is 950 ft long with a beam of 106 ft. The design ship for the proposed channel improvements was the *Susan Maersk*. The *Susan Maersk* is a post-Panamax S-class containership with a length of 1,140 ft and a beam of 140 ft. For ship simulation, the *Susan Maersk* is assumed to be loaded to a draft depth of 47.5 ft.

A reconnaissance trip to Savannah Harbor was made on December 3 through 5, 2001, to observe navigation conditions in the Savannah River. The project site was photographed to create the simulation visual scene using digital video and still cameras. Information concerning problem areas and pilot practices was obtained during the inbound transit of the *Ludwigshafen Express* on December 3 and the *Hanjin Tokyo* on December 5. The vessels were tracked using a handheld global positioning unit.

The *Ludwigshafen Express* is a Panamax containership, 965 ft in length overall with a beam of 105 ft. The ship's draft was 35 ft. The transit was conducted at high water, estimated to be +9 ft MLLW. Typically, high water is +8 ft MLLW. The ship was turned in the Kings Island Turning Basin prior to docking at the Georgia Ports Authority (GPA) Port Wentworth Terminal. The *Hanjin Tokyo*, a Panamax ship, which had a draft of 34 ft. The transit commenced approximately 2 hours after low tide and was also terminated at the GPA Port Wentworth Terminal.

The following insights to the navigation conditions on the Savannah River were offered by the pilots during the transits:

- Wind-driven currents occur in the Atlantic, typically with a wind from the south/southwest and combined with flood tide. The crosscurrents occur in the two easternmost channel segments of the entrance channel.
- The currents are usually aligned with the channel in the protected portions of the river.
- Widening the Long Island Crossing Range by 100 ft on the south would provide additional room for meeting.
- Ships are restricted to minimum underkeel clearance of 4 ft in the entrance and 2 ft in the inner harbor, according to US Coast Guard guidelines.
- A new liquefied natural gas (LNG) facility and turning basin were under construction along the south side of Upper Flats Range. The turning basin is not part of the channel improvements being

evaluated by this study. Ships will not meet near the facility when an LNG tanker is docked. It should be noted that the construction of the LNG facility and turning basin was completed after the ship simulator study was initiated.

- Two-way traffic occurs over most of the project at the pilots' discretion. Pilots try to time their meetings for the straight reaches and avoid meeting at City Front or the Bight Channel.
- Ships are affected by currents in an area inside the entrance channel jetties and another near Fort Jackson due to currents ebbing from Back River.
- Ebb-tidal currents work against inbound ships when making the turn from the Bight Channel to Fort Jackson Channel.

### 6.3.2.1 Proposed Channel Improvements

The ship simulator model investigation documented in the report titled *Navigation Study for Savannah Harbor Channel Improvements* was conducted by ERDC in Vicksburg, MS. The simulator experiments were performed during September and October 2003 by personnel of the Coastal and Hydraulics Laboratory (CHL) and river pilots from the Savannah Pilots Association. During the course of the model study, representatives of the Savannah District and other navigation interests visited ERDC to observe the simulator and discuss tests results. Both the existing and the 48 ft project channels were modeled. Two-way traffic on both maximum ebb and flood tide conditions were tested. The currents were calculated using the TABS-MD model. The ship models used in the simulator study were the *Susan Maersk* loaded to a 47.5-foot draft and the *SL Performance* loaded to a draft of 33 ft. The simulators were coupled together for two-way traffic conditions and tugs and bow thrusters were available to the pilots during the simulation runs. Various combinations of tides and vessels were tested for meeting situations.

Savannah District provided ERDC with a proposed channel design based on deepening the existing navigation channel on the existing side slopes and recommended bend wideners in areas that required additional width as determined by design standards in EM 1110-2-1613, *Hydraulic Design Guidance for Deep-Draft Navigation Projects*. Alternatives that were developed from this design are as follows:

#### Plan 1

- Deepening the navigation channel on existing side slopes
- Bend wideners in turns
- Shifting Ft Jackson Range eastward to avoid impact to pipeline
- Bend widener in transition area between Ft Jackson and Oglethorpe Range

#### Plan 2 – Same as Plan 1 with the following exceptions:

- Long Island Range – Additional channel width for meeting area on south side of range
- Ft Jackson Range – ERDC recommended abandoning triangular portion on north side of channel

#### Plan 3

- Deepening on existing channel toes (maintaining existing width)

ERDC modeled these three plans in ship simulation and developed a recommended plan based on pilot navigation of the alternatives. A detailed description of the plans and ERDC's recommended revisions for an optimum channel design are discussed below.

The changes to the horizontal channel limits are presented, beginning with the entrance channel and proceeding inland. Unless otherwise indicated, these changes are part of Plan 1. The existing Tybee Range is 600 ft wide. Deepening to 48 ft on the existing side slopes will narrow the proposed channel to approximately 550 ft. The west side of the turn onto Bloody Point Range is deepened on the existing side slope resulting in a channel width reduction of 25 ft on the west side. To facilitate navigation, the Savannah District has proposed a 75 ft widener on the east side of the turn. The Bloody Point Range is presently 600 ft wide. The 25-ft reduction on each side caused by deepening on the existing side slopes will narrow the channel to approximately 550 ft. The Jones Island Range, which is the turn from Bloody Point Range to Tybee Knoll Cut Range, was reduced by 25 ft on the north side, but the Savannah District proposal widened the channel by 75 ft on the south. Therefore, the width of Jones Island Range was increased from 700 ft to 750 ft. Tybee Knoll Cut Range is presently 500 ft wide. Deepening to 48 ft on the existing side slopes reduced that width to 450 ft.

The New Channel Range is 500 ft wide. The proposed 48-ft channel will narrow New Channel Range to 450 ft. The west side of the turn onto Long Island Crossing Range is deepened on the existing side slope and thus the channel width is reduced by about 25 ft on the west side. However, the District has proposed a 75 ft widener on the east side of the turn. The Long Island Crossing Range is presently 500 ft wide. There are two proposed widths for Long Island Crossing Range. Plan 1, deepened upon the existing side slopes, reduces the channel width to 450 ft. Plan 2, widens the western side of the Long Island Crossing Range deepened channel by 100 ft, thus increasing the channel width to 550 ft. Plans 1 and 2 were identical for the reaches immediately east and west of Long Island Crossing Range. The existing Lower Flats Range is 600 ft wide. The proposed Plan 1 widened the north side of Lower Flats Range by 75 ft. The south side of Lower Flats Range was narrowed by 25 ft due to deepening on the existing side slope. Therefore, the Plan 1 Lower Flats Range is 650 ft wide. The District has provided an additional 150 ft on the west side of the turn between Lower Flats Range and Upper Flats Range. The east side of the turn was narrowed by 25 ft due to deepening on the existing side slope. The Upper Flats Range is 550 ft wide. The proposed Plan 1 Upper Flats Range was widened by 75 ft on the west side. The east side of the proposed Plan 1 Upper Flats Range was narrowed by 25 ft due to deepening on the existing side slope. Therefore, the Plan 1 Upper Flats Range was 600 ft wide.

The Bight Channel is currently a series of 800 ft wide segments. The north side of Plan 1 Bight Channel was narrowed by 25 ft due to deepening on the existing side slope. The south side of the Plan 1 Bight Channel was widened 75 ft. Thus, the Plan 1 Bight Channel is 850 ft wide. The channel immediately west of The Bight Channel, the Fort Jackson Reach, was realigned to avoid relocating pipelines. The first proposed alignment, Plan 1, shifted the channel to the east and provided a large triangular area for the ship's stern to swing when heading outbound. However, concern over inbound ships using the triangular area and then running aground because they were too far west led to Plan 1 being abandoned and Plan 2 being developed. Plan 2 removed the large triangular area. Plan 3 is the existing channel deepened to 48 ft. Plan 3 did not deepen on the existing side slopes, so its footprint is the same as the existing Fort Jackson Range.

There was only one proposed deepening plan each for Oglethorpe Range and the Wrecks Channel. Both plans deepened on the existing side slopes. This reduced the width of both deepened channels from 500 to 450 ft. A 75 ft widener was proposed for the turn at the western end of the Wrecks

Channel. A second plan, Plan 2, was developed without the widener. The existing turn was deepened along its side slopes, thus reducing the south side of the turn by 25 ft. Plan 1 also widened the turn east of City Front Channel by 75 ft on the north side.

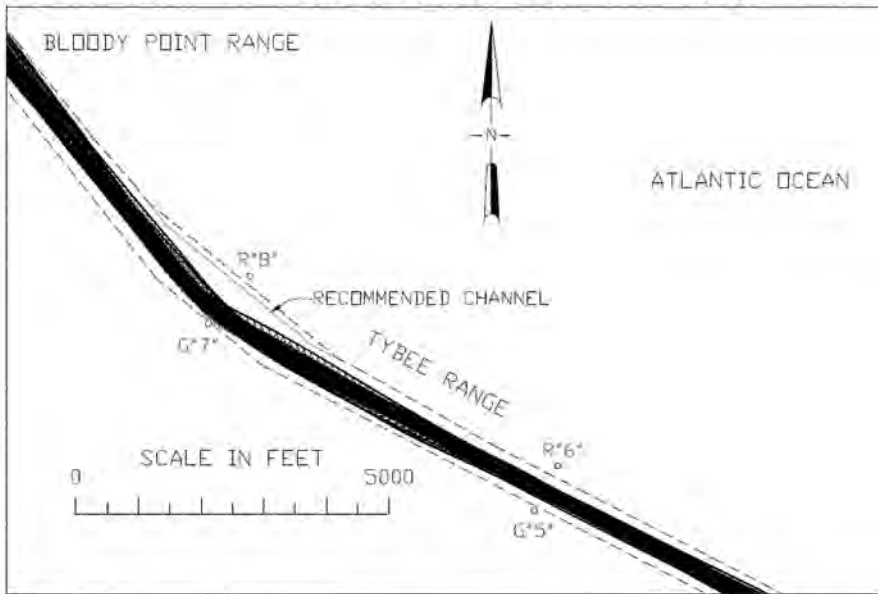
The turn between City Front Channel and Marsh Island Channel was widened by 75 ft as part of Plan 1. The remainder of Marsh Island Channel was deepened on the existing side slopes, thus reducing the channel width from 500 to 450 ft. Plan 1 widens the turn between Marsh Island Channel and Kings Island Channel by 75 ft on the north side. The remainder of Kings Island Channel was deepened on the existing side slopes, thus reducing the channel width from 500 to 450 ft. The north side of Kings Island Turning Basin was widened by 75 ft. The rest of the basin was reduced by 25 ft by deepening along the existing side slopes.

### 6.3.2.2 Recommendations

Recommendations from the ship simulation study are presented below in order from the Atlantic Ocean, heading inland.

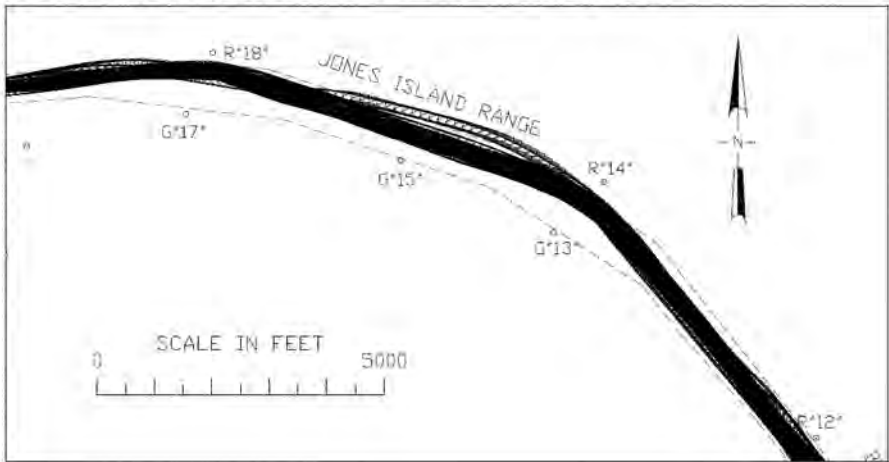
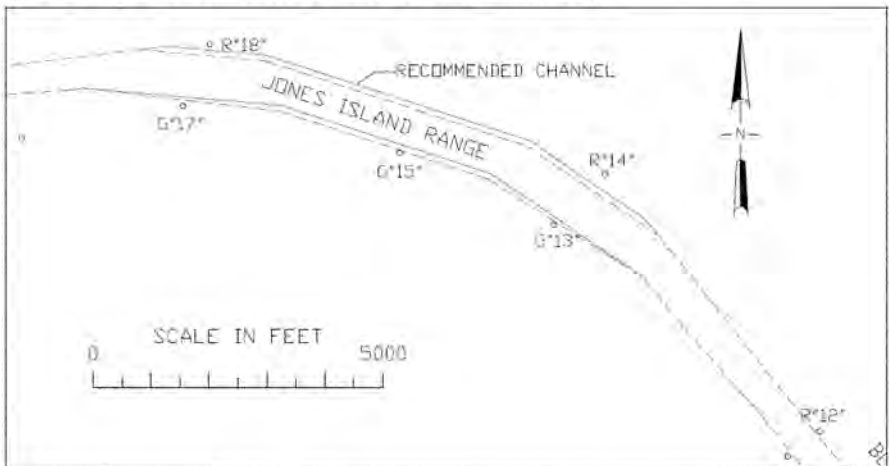
ERDC recommends that the Tybee Range Channel may be improved as per the Plan 1, which specifies that the range be deepened on its existing side slopes. Deepening to 48 ft on the existing side slopes will result in a 550 ft wide channel. The widener on the north side of the turn between Tybee Range and Bloody Point Range that was included as part of Plan 1 was not used during any of the S-class simulations. Therefore, it is recommended that the channel be deepened on its existing side slopes as shown in **Figure 6.3.2.2-1**.



**Figure 6.3.2.2-1: Recommended Turn with Tracks of All S-Class Containership Simulations**

ERDC recommends that the Bloody Point Range be improved as per Plan 1 by deepening the range on its existing side slopes.

Plan 1 widened Jones Island Range on the south side. However, the simulated vessels showed a strong tendency to stay to the north side while making the turn between Tybee Knoll Cut Range and Bloody Point Range (**Figure 6.3.2.2-2**). Therefore, it is recommended that the widening be shifted to the north side of Jones Island Range as shown in **Figure 6.3.2.2-3**.

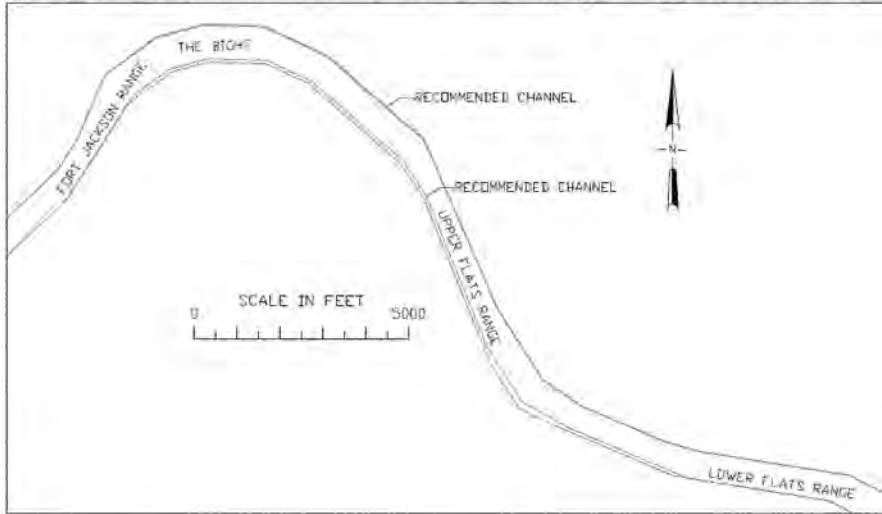
**Figure 6.3.2.2-2: Jones Island Range, All S-Class Containership Tracks****Figure 6.3.2.2-3: Recommended Widener for Jones Island Range**

The Tybee Knoll Cut Range and the New Channel Range may be deepened to 48 ft on their existing side slopes as simulated for Plan 1 conditions.

The wider Plan 2 channel is recommended for the Long Island Range. This is a long reach, fairly centrally located in the project. Providing the extra width will provide an excellent area for meeting of extremely large ships.

The Plan 1 channel is recommended for the Lower Flats Range which widens the east side of the channel by 75 ft. The pilots did not use the widening on the west side of the turn between Lower and Upper Flats Ranges or on the west side of the Upper Flats Range or on the south side of the Bight Channel as proposed in Plan 1. Therefore, the 48 ft channel can be deepened on the existing toe limits in this area (Figure 6.3.2.2-4). Ships tended to stay to the north side of The Bight Channel. It is recommended that this area not be deepened on the existing side slopes but be deepened on the existing channel toe to provide adequate width in this reach.

**Figure 6.3.2.2-4: Channel recommendations Lower Flats Range through The Bight Channel**



The Plan 2 channel is recommended for Fort Jackson Range. The additional 100 ft will provide a safe meeting area that the pilots can use with confidence. The pilots consistently relied upon the additional width for two-way traffic during the simulations. Fort Jackson Range is long enough that the pilots can easily coordinate meeting there if necessary.

Because of the ships' tendency to leave the channel a bit on the north side, it is recommended that the north side of Oglethorpe Range and Wrecks Channel not be deepened along the existing side slope but be deepened on the existing toe limits.

None of the wideners on the Wrecks Channel/City Front Channel area specified in the Plan 1 design were used. They may be omitted from the 48-ft project.

The proposed 1,600-ft-diameter Kings Island Turning Basin is adequate for turning the *Susan Maersk*. It is recommended that the basin be dredged as proposed.

### 6.3.3 Meeting Areas

Meeting areas provide areas for the design vessels to be able to meet in transit to avoid delays that would otherwise be incurred if a vessel had to either wait in the entrance channel or at dock until a design vessel had exited the channel. For Savannah Harbor, all “passing” lanes are defined as meeting areas. “Passing” is typically defined as ships overtaking each other. “Passing” in this sense is not practiced in Savannah Harbor; therefore, any subsequent reference to “passing” shall be understood as “meeting”.

From discussion with the Savannah Harbor pilots, pilots “can meet all vessel classes using the harbor now including two post Panamax vessels, but that is rare and will take a significant amount of coordination”. This coordination produces delays in sailing times for other vessels as meetings can only occur at certain wider areas of the channel and cannot occur in turns or where vessels are docked at berth.

Due to changes in the channel width and the handling capability of the deeper draft post Panamax vessels, the pilots requested that meeting areas be included in the project to ensure greater flexibility in vessel movement. The pilots indicated that the lengths for meeting areas need to be at least 2,000 ft long but preferably 3,000 ft.

#### 6.3.3.1 Locations

During the initial stages of the SHEP navigation study, the harbor pilots expressed a need for a meeting area and suggested the Long Island Range (Station 16+500 to 19+500) as a long straight reach that would be appropriate. As a result, this area was incorporated in the ship simulation study and was used successfully by the pilots in simulation runs.

During the simulation runs, pilots typically met in the Fort Jackson range using a widened portion of the design channel as a meeting area. As a result, the navigation study recommended this area to be used as a meeting area. Pilots had requested Oglethorpe Range (Station 55+000 to 58+000) be considered as a meeting area being centrally located on a long straight reach. A meeting area was added on the north side of the range.

In a subsequent meeting with the pilots, a need was expressed for a meeting area across from the CITGO dock. Initial design was a 3,000 ft meeting area that runs through the Marsh Island Turning Basin (89+934 to 92+000). Subsequent investigation limited this area to 2,200 ft to avoid impact to an International Paper effluent pipeline. This area was eventually removed from consideration as attempts to provide more adequate length for a meeting area would have produced considerable upland taking of real estate.

The first two areas identified above were analyzed in the HarborSym economic model to determine their economic justification to be included as part of the Savannah Harbor Expansion project. A discussion of this analysis is included in the Economic Appendix.

### 6.3.3.2 Ship Simulation Verification

A follow-up ship simulation was conducted January 14-23, 2009 at ERDC to determine the following:

- The necessary length for meeting on Long Island Range.
- If the proposed meeting area on Oglethorpe Range was adequate in length.
- If narrowing the navigation channel above Marsh Island to provide adequate berth width for the design vessel would adversely affect the pilot's ability to navigate that range or hamper their ability to turn vessels in the Kings Island Turning Basin.

Two pairs of pilots visited the facility to run the ship simulator using the revised meeting area designs. Model runs and pilot's input via questionnaires were used to determine final meeting area design. The results are as follows:

Long Island Range – Based on post processing of the model runs and pilot input, ERDC determined that a 100 ft wide and 8,000 ft length meeting area would be required for vessels to meet safely with 1,000 ft transitions back to the navigation channel width. Final location (center of range) was determined by consultation with pilots. Location was determined to be from Station 14+000 to Station 22+000 for the full 100 ft meeting area (Station 13+000 to 23+000 including transitions).

Oglethorpe Range – Adequacy of the initial proposed length of 3,000 ft had been questioned during the August 2008 Alternative Formulation Briefing (AFB). Therefore, the length of the meeting area was extended by 1000 ft for ship simulation. A width of 100 ft from Station 54+800 to Station 58+800 (Station 54+800 – Station 60+700 with transition) for the range was used in simulation runs and determined to be adequate. Track plots showed that pilots required the full length so no further restriction in length was tested and a full length of 4,000 ft is recommended.

Pilots successfully navigated restricted channel at the Marsh Island Range and approach into Kings Island Turning Basin was not affected.

### 6.3.4 Entrance Channel Extension

In 1997, the original hydrographic survey for the entrance channel extension, which was conducted in association with the SHEP, extended 25,000 ft beyond the existing end of the Federal project, which occurred at Station -60+000. That survey also extended approximately 3,000 ft oceanward of the 50 ft below MLLW contour, the depth necessary for the deepest entrance channel alternative that was being considered in the feasibility study. At the oceanward extent of the hydrographic survey, the water depth was consistently deeper than 54 ft below MLLW at that time and no additional surveys were conducted. Given that an adequate depth was verified beyond the 50 ft contour below MLLW, it was recommended at the time that the entrance channel be extended 25,000 ft for the 50 ft channel depth (to Station -85+000).

After review of the most current NOAA Chart#11512, it was determined that some shallower shoals exist offshore of the original 1997 survey area. The District obtained and evaluated existing NOAA surveys and conducted a bathymetric survey the week of October 19, 2009. The new survey indicates

that there are additional shoals offshore, beyond the end of the entrance channel as it is currently designed based on the 1997 hydrographic surveys.

Additional entrance channel extension routes were developed with the goal of providing the most direct, safest and most cost effective route from the vicinity of the current entrance channel to the 50 ft contour below MLLW either north or south of the current and proposed entrance channel. The length of the extension is dependent upon design channel depth and alignment. Changes to the entrance channel configuration will require additional aids to navigation.

#### 6.3.4.1 Alternative Routes

Due to the similarity of ocean sediments surrounding the entrance channel, it is expected that sediments in the new reach would be similar to those found between Stations -60+000 and -85+000 in the previously proposed alignment. Confirmatory sampling is required through additional channel borings during the PED phase of the project. Previous data suggests that the entrance or ocean bar channel sediments are primarily sand, with exceptions between the jetties and at Station -45+000, which have large silt and clay components.

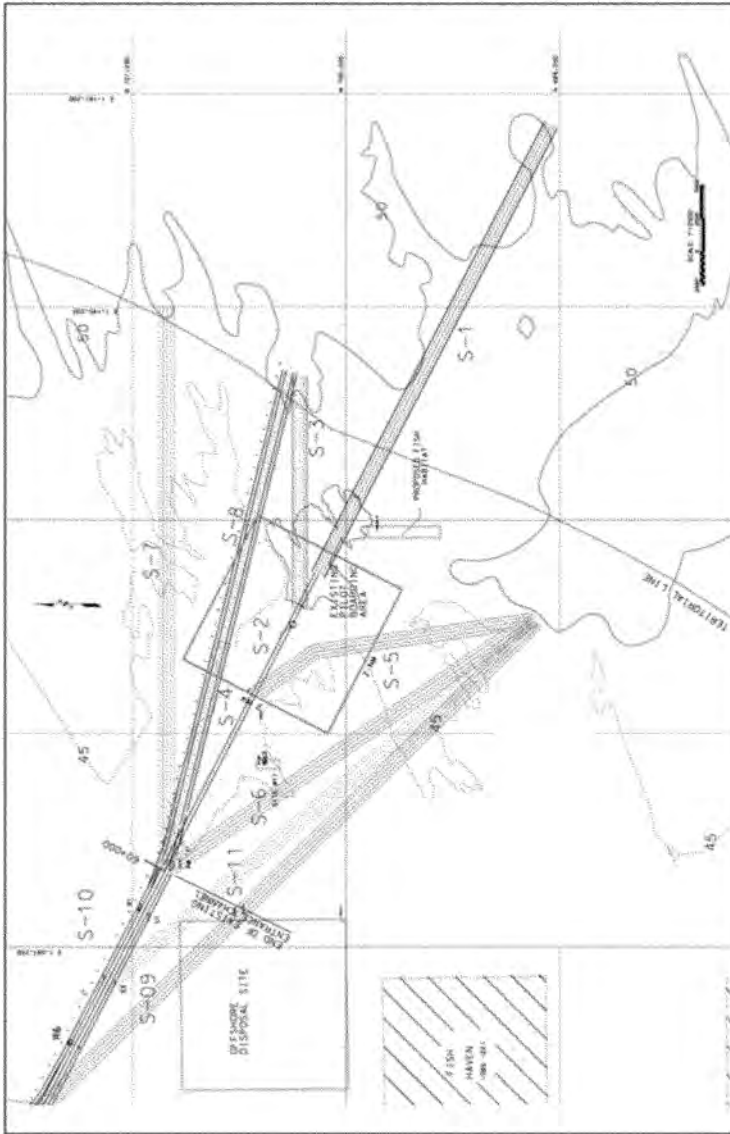
In addition to consideration of the sediment characteristics found in the new channel extension, consideration was also given to cultural resources and environmental impacts. Impacts to cultural resources are not expected this far offshore; however, surveys will be conducted during PED to confirm or refute this assumption. Environmental impacts to endangered species (Right Whales) were also considered. Details of this analysis can be found in the EIS.

Eight alternative channel routes were developed for consideration. See **Figure 6.3.4.1-1**. These routes were designed from the beginning of the current entrance channel (Station -60+000) out to the 50 ft contour below MLLW. Route S-08 was developed as a result of input from the Savannah Bar Pilots. **Table 6.3.4.1-1** shows the dredging volumes for the four least costly alternatives.

**Table 6.3.4.1-1: SHEP Entrance Channel Extension Route Alternatives (Description and Quantities)**

| Route Description                                 | Route | Volume<br>cubic yards<br>(-49 ft MLLW) | Volume<br>w/Over-depth<br>cubic yards<br>(-51 ft MLLW) |
|---------------------------------------------------|-------|----------------------------------------|--------------------------------------------------------|
| Straight Line -60+000 to -123+000                 | S-01  | 1,235,481                              | 2,988,367                                              |
| -60+00 to -82+000 S-3, then east to -50 ft MLLW   | S-03  | 957,870                                | 2,409,643                                              |
| -60+000 to -78+000 S-5, then South to -50 ft MLLW | S-05  | 1,861,076                              | 3,646,245                                              |
| -60+000 on tract ESE S-8 to -50 ft MLLW           | S-08  | 2,041,954                              | 3,401,689                                              |

Figure 6.3.4.1-1: SHEP Entrance Channel Extension Route Alternatives



### 6.3.4.2 Ship Simulation for Channel Extension

In November 2009, the District contacted ERDC to conduct additional simulations for two different alignments for the Entrance Channel. The alignment changes, or doglegs, were proposed so that when the Entrance Channel is deepened, it will reach naturally deep water in a shorter distance, reducing dredging costs and transit times. This study focused on alignments S-3 and S-8.

The simulation databases from the earlier study were modified to reflect alignments S-3 and S-8. Currents and waves for the proposed alignments were modeled in separate ERDC studies. These documents are being finalized and will be included in the Final SHEP documents. Maximum flood and ebb currents from the hydrodynamic model were added to the simulator database. Bend widenings were added to both alignments. Inbound ranges were also built for each alignment in the visual scene and radar.

Results from the simulation are as follows:

- Without ranges, alignment S-3 was not adequate for the design vessels. This is true for the alignment with and without the bend widener.
- The addition of inbound ranges improved both alignments.
- Alignment S-8 appeared to be adequate for one-way traffic, even without ranges. The addition of ranges and the bend widener allowed for meeting of a Panamax ship with a post-Panamax ship.
- Crabbing occurs in adverse wind conditions. Under the conditions tested, crabbing was not a serious issue. Neither alignment made crabbing more severe.
- Alignment S-8, with ranges and the bend widener, was recommended by the ship simulation study.

### 6.3.4.3 Selected Channel Extension Route

Through the planning process, the 8 entrance channel extension routes were evaluated with the goal of selecting the most direct, safest and most cost effective route from the vicinity of the current entrance channel to the 50 ft contour below MLLW either north or south of the current and proposed entrance channel. The length of the bar channel extension varies with the proposed depth alternative (**Table 6.3.4.3-1**). This process, along with ship simulation verification, resulted in the recommendation of Route S-08 for selection as the entrance channel extension. **Figure 6.3.4.3-1** illustrates the maximum 38,600 foot long extension of the ocean bar channel from Station -60+000 to -98+600 for the 48-foot depth alternative.

**Table 6.3.4.3-1: Length of Channel Extension Required for Depth Alternatives**

| Depth Alternative | Channel Extension Stationing | Length of Extension |
|-------------------|------------------------------|---------------------|
| 44                | -60+000 to -95+680           | 35,680 ft           |
| 45                | -60+000 to -96+880           | 36,880 ft           |
| 46                | -60+000 to -97+510           | 37,510 ft           |
| 47                | -60+000 to -97+680           | 37,680 ft           |
| 48                | -60+000 to -98+600           | 38,600 ft           |





Prior to construction, additional core borings for sediment characterization and a cultural resources impact analysis of the route and sediment placement sites will need to be completed. The additional borings are located along the new alignment (S-08) to determine material types to be dredged. Nineteen borings will be drilled at approximately 2,000-foot intervals as shown on the drawing titled, *Channel Extension Boring Locations*, which is included in the Engineering Investigations Supplemental Materials. The Standard Penetration Test (SPT) borings will be drilled to at least 60 ft below MLLW. According to borings drilled along the previous extension alignment to the South, the material to 60 ft below MLLW is expected to be predominately sand. Since the silty, clayey fine sands of the top of the Miocene confining layer are known to exist at around 55 to 60 ft below MLLW in this area, some of the borings will likely bottom out in this material. For additional detail on dredging and annual maintenance of the entrance channel extension see Section 11.0 and 12.0.

#### 6.3.4.4 Vertical Motion Study

A vertical ship motion study was conducted by ERDC to evaluate channel depth requirements. Detailed results are documented in two reports titled 1) *Navigation Study for Savannah Harbor Channel Improvements* and 2) *Vertical Ship Motion Study for Savannah, GA Entrance Channel* which are included in the Engineering Investigations Supplemental Materials.

The first study, *Navigation Study for Savannah harbor Channel Improvements*, consisted of a series of simulations with a computer-controlled ship transiting Tybee Range. This study was conducted to evaluate extending Tybee Range from Station -60+000 to -85+000 on new channel option S-1 shown in **Figure 6.3.4.1-1**. Two drafts of the *Susan Maersk* were simulated, 46 ft and 47.5 ft. Wave conditions for this study were selected based upon a concurrent wave model study conducted at ERDC. Based upon analysis of the 35% highest waves, the following conditions were chosen for the study:

- Waves coming from a direction of 215 degrees
- Wave heights of 6, 8, and 10 ft were simulated
- Wave periods of 8 and 10 seconds were simulated

Water depths from 48 to 56 ft were simulated in 1-foot increments. Water depth is defined as the authorized channel depth plus tide. Therefore, a water depth of 54 ft could represent either a 54-ft channel at low water or a 50-ft channel with a 4-foot tide.

The vertical motion model used in the study was developed by Tracor Hydronautics and operated in fast-time. The simulated ship maneuvered with computer-controlled speed and heading based upon input conditions. Results show that for the *Susan Maersk* at a 47.5-ft draft, grounding would occur in a 52 ft channel depth under conditions at or worse than a 6 ft wave height and 8 second wave period. Also, for the *Susan Maersk* at a 46-ft draft, grounding would occur in a 51 ft channel depth under conditions at or worse than a 10 ft wave height and 10 second wave period. Harbor pilots attempting transit under these sea states would wait for additional depth from tides.

Some shallower offshore shoals were discovered that might influence the safety and efficiency of navigation if the project proceeds as originally proposed. The U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), conducted a vertical ship motion study to evaluate three proposed channel alignments S-1, S-3, and S-8. These alignment changes (doglegs) are proposed to allow ships to reach deeper water in less distance, with reduced dredging costs. This second study, *Vertical Ship Motion Study for Savannah, GA Entrance Channel*,

incorporated findings from the first study for wave height transformation and transformation factors. The Channel Analysis and Design Evaluation Tool (CADET) was used to predict vertical ship motions due to wave-induced heave, pitch and roll. PIANC and Ankudinov ship squat were calculated and compared with the CADET/BNT squat predictions. The CADET squat formula is based on the work of Beck, Newman, and Tuck. The CADET days of accessibility, vertical motion allowances, and net underkeel clearance (net UKC) were calculated based on these vertical ship motion components to provide a risk-based or probabilistic method of evaluating different channel depths.

Based on the separate economic study for the Savannah Harbor Expansion Project, a final proposed project depth of 49 ft was selected for the Outer Channel. This represents a 1 ft reduction in the original project depth of 50 ft used in this engineering study. However, since the range and duration of the tides is sufficient to increase water levels to accommodate safe transits for the ship drafts discussed in this study, results are still valid and accurate. Water depths were adjusted for the tides and discussed as necessary in this report.

A joint probability distribution of wave height and period was created in ten 22.5 degree direction bands from 11.25 degrees to 236.24 degrees. It consisted of 158,138 observations representing 90.2% of the deepwater data from the WIS 20-year hindcast buoy (WIS370). A total of 99 empirical directional wave spectra were created from this joint probability distribution. Parameters for these directional spectra were based on wave period and height for a TMA frequency spectrum and Cos<sup>n</sup> directional spreading function. The spectra wave heights were reduced at each reach along the Savannah Channel according to the previous study results of Thompson.

The Ship Tow Simulator (STS) requires the wave period, height, and direction combination at stations along the channel to prepare wave cases for each simulation run. Since it is impractical to model multiple wave cases in the STS, the most representative wave cases were selected based on the 3-5 % highest waves in the 20-year hindcast at deepwater station WIS33. Values from an earlier study using the STWAVE transformation model were provided for Stations 0 to 87 in all channel options including the Existing channel. These data were then extrapolated seaward to Station 99 for the new channel options S-1, S-3, and S-8.

Ship squat was compared for PIANC, Ankudinov, and CADET/BNT predictions. The five PIANC empirical squat formulas included those of Barrass, Eryuzlu, Huuska, Römisch, and Yoshimura. The Ankudinov formula was originally used in the STS. Based on ship velocity, an average squat value was determined from these methods to be used for channel design.

This report summarizes remaining underkeel clearance(net UKC) for the average and maximum (or worst case) ship squat predictions. For the light-loaded *Susan Maersk* drafting 46 ft at the shallowest water depth of  $h=50$  ft (+1 ft tide), pilots should proceed with caution if attempting ship speeds faster than 10 to 12 knots (kt), especially if any significant wave activity is present. For water depths greater than 50 ft, there should be sufficient net UKC for speeds as high as 14 to 16 kt. For the fully-loaded ship drafting 47.5 ft at this shallow 50 ft depth (+1 ft tide) depth, pilots should exercise extreme caution if attempting to move at speeds as high as 10 kt. This speed is probably not even possible unless wave heights and periods are relatively small. For the deeper depths when tides are present, the available underkeel clearance should be sufficient up to speeds of 12 to 14 kt. Of course, pilots should be vigilant at higher speeds as ship squat can always be reduced by slowing down.

In general for both light- and fully-loaded ships, days of accessibility increase for slower ship speeds, outbound transits, interior reaches, and reduced loads/lesser drafts. The minimum depths are 50 and 52 ft (+3 ft) for the light- and fully-loaded ships, respectively. Based on the CADET analysis of underkeel clearance and the corresponding days of accessibility, the S-8 alternative is the best option among the three choices S-1, S-3, and S-8, and much better than the existing channel. The S-8 option will probably have slightly less risk of grounding than S-1 and S-3.

Based on the CADET tidal analysis for the light-loaded ship, the Savannah entrance channel will have an additional water level of +1 ft above the 49 ft proposed project depth (i.e.,  $h=50$  ft) for durations of 8 hr for 365 days (i.e. 100 percent) of every year. To accommodate the fully-loaded ship, an additional water level of +3 ft above the 49 ft proposed project depth (i.e.,  $h=52$  ft) will be required. This depth will have durations of 6 hr for 365 days (i.e., 100 percent) of every year, but decreases to only 25 days per year for 8 hr durations. Water depths of 53 to 57 ft will have continually decreasing durations from 4 hr (365 days per year) to 1 hr (7 days per year).

Thus, for the recommended S-8 option in Reach 1, the light-loaded 46-ft-draft 46 ft draft *Susan Maersk* in a depth of 50 ft (+1 ft tide) will have a total of 360 days of accessibility per year during inbound transits at 10 kt. At this depth, tide levels are not a problem as the Outer Channel will have 8-hr durations for 365 days per year, more than sufficient to accommodate transit times. Increased ship speed can be accommodated with decreasing durations of 7 hr or less as the tide level increases. For instance, 338 days per year are predicted for inbound transits at 14 kt at 50 ft depth. A tide level increase of 3 ft to a depth of 52 ft will accommodate inbound transits at 14 kt for 356 days per year. However, this water level is only available for 6 hr durations every day of the year at this depth of 52 ft. Durations up to 8 hr are available but only for 25 days per year. Using the percentage of tide level fraction, this is equivalent to reduced days of accessibility of only 24 days per year (i.e.,  $356 \text{ days} * 25 \text{ days/yr}/365 \text{ days/yr}$ ).

Similarly, for the recommended S-8 option in Reach 1 for the 47.5 ft draft *Susan Maersk*, a depth of 52 ft will provide a total of 360 days of accessibility per year during inbound transits at 10 kt. At this depth, tide levels are available every day of the year for durations up to 6 hr. If necessary, a duration of 8 hr is available for 25 days a year. As before, this is equivalent to a reduced days of accessibility of only 24 days per year for this 8-hr duration. Increased ship speed can be accommodated with decreasing durations of 6 hr or less as the tide level increases above a depth of 52 ft. For instance, 357 days per year are predicted for inbound transits at 14 kt at 52 ft depth. A tide level increase of +4 ft to a depth of 53 ft will accommodate inbound transits at 14 kt for 362 days per year. This water level is only available for 4 hr durations every day of the year at this depth of 53 ft. Durations up to 6 hr are available, but only for 144 days per year. The equivalent reduced days of accessibility for these conditions is 43 days per year (i.e.,  $362 \text{ days/yr} * 144 \text{ days/yr}/365 \text{ days/yr}$ ). Increasing the depth by 5 ft to 54 ft would provide 364 days per year accessibility, but only for a duration of 4 hr for 242 days per year to 3 hr for 331 days per year. In this case, the equivalent reduced days of accessibility is only 241 days per year (i.e.,  $364 \text{ days/yr} * 242 \text{ days/yr}/365 \text{ days/yr}$ ).

Wave-induced vertical ship motions are composed of the combined effects of heave, pitch, and roll at the five critical points on the bottom of the ship. CADET calculates these vertical motion allowances for each ship loading condition, channel reach, and water depth. In general, outbound transits are much less of a problem than inbound transits as their motion allowances are much smaller. For the light-loaded ship, the motion allowances tend to increase as ship speed increases. The motion allowances for the fully-loaded ship, however, tended to decrease until reaching a ship speed of about

12 kt before increasing again at the highest speeds. These comparisons indicated that the S-8 option is the preferred alternative as it has smaller predicted motions than the existing S-1 or the S-3 option for all speeds, especially for 10 kt.

The net UKC is obtained by subtracting draft, squat, and ship vertical motion allowances from the water depth (i.e., net UKC = gross UKC – squat – ship vertical motion allowance). In general for the light- and fully-loaded *Susan Maersk*, net UKC increases with change in transit direction from inbound to outbound, increases in water depth, and decreases in speed. The S-8 option is as good as or better than the existing S-1 and S-3 option channel configurations.

For the light-loaded inbound ship at a speed of 10 kt, only twelve of the 99 waves indicated grounding conditions at the recommended depth of 50 ft (+1 ft) based on the accessibility results. These 12 waves represent relatively rare occurrences, as all of them only occur for a total of 4.9 days/yr. For the fully-loaded inbound ship at a speed of 10 kt, only seven waves indicated possible grounding conditions at the recommended depth of 52 (+3 ft) ft from the accessibility results. These seven waves also represent relatively rare occurrences with a total of only 2.6 days/yr. These are relatively large wave periods and heights compared to the typical waves at Savannah, but pilots should be particularly aware of possible grounding conditions when they occur.

The wave-induced vertical motion allowances and corresponding net UKC support and confirm the days of accessibility results for the minimum water depths required for safe transits in both inbound and outbound directions. In summary, a depth of 50 ft (+1 ft) is the minimum acceptable depth for safe transits at 10 kt for the light-loaded, 46-ft-draft *Susan Maersk* in the Savannah Outer Channel. A minimum depth of 52 ft (+3 ft) is required for safe transits at 10 kt for the fully-loaded, 47.5-ft-draft *Susan Maersk*. Faster ship speeds up to 14 kt are possible if higher tide levels are used, but the available durations are reduced such that a transit may not be possible every day of the year.

### 6.3.5 Bend Wideners

#### 6.3.5.1 Location

Based on design standards in EM 1110-2-1613, *Hydraulic Design Guidance for Deep-Draft Navigation Projects*, the District proposed bend wideners in the initial channel design to accommodate the design vessel *Susan Maersk*. Bend wideners included an additional 100' from the bottom of the design channel toe and are listed in **Table 6.3.5-1** under column heading "Savannah". A total of 10 bend wideners were proposed (8 inner channel and 2 entrance channel). An additional 100' on the backside of Kings Island Turning Basin was also included as a design feature.

#### 6.3.5.2 Ship Simulation Verification

As a result of ship simulation, ERDC determined that only 3 of the bend wideners would be required to accommodate the design vessel. The location of one of the proposed wideners (Long Island Range) was shifted from the south to the north side of the range. Those bend wideners are listed in **Table 6.3.5-1**, column heading "ERDC". Of the remaining 7 proposed bend wideners, ERDC determined that deepening those ranges on the existing width would provide sufficient channel width for the design vessel and are also listed under the column heading "ERDC" marked with an asterisk(\*). Ship

simulation also confirmed the need for the additional 100' width on the back side of the Kings Island Turning Basin.

**Table 6.3.5-1: Proposed and Recommended Bend Wideners**

| Range#         | Range/Reach Name                                                     | Station(Approx)            | Savannah          | ERDC              |
|----------------|----------------------------------------------------------------------|----------------------------|-------------------|-------------------|
| 0a             | Tybee/Bloody Pt                                                      | -41+000 to -38+000         | Yes/North         | No*/North         |
| <b>1a,2,2a</b> | <b>Jones Island</b>                                                  | <b>-23+000 to -14+0000</b> | <b>Yes/South</b>  | <b>Yes/North</b>  |
| 6              | New Channel/<br>Long Island Crossing                                 | 9+500 to 11+500            | Yes /North        | No*/North         |
| <b>9</b>       | <b>Lower Flats</b>                                                   | <b>27+500 to 31+500</b>    | <b>Yes /North</b> | <b>Yes /North</b> |
| 10 To 20       | Upper Flats/Bight/<br>Ft Jackson                                     | 31+000 to 52+500           | Yes/South         | No*/South         |
| <b>20,21</b>   | <b>Ft Jackson &amp; Transition</b>                                   | <b>52+500 to 55+000</b>    | <b>Yes /North</b> | <b>Yes /North</b> |
| 24,25          | Wrecks Channel                                                       | 65+500 to 66+500           | Yes /South        | No                |
| 25,26,27       | Wrecks Channel/City Front                                            | 69+000 to 71+500           | Yes /North        | No*/North         |
| 31             | City Front/Marsh Island                                              | 76+000 to 78+000           | Yes /North        | No*/North         |
| 34,35          | Marsh Island Turning Basin                                           | 87+500 to 90+000           | Yes /North        | No*/North         |
|                | <b>Kings Island Turning<br/>Basin Back (South<br/>Carolina) Side</b> | <b>99+000 to 100+500</b>   | <b>Yes</b>        | <b>Yes</b>        |

\*Deepen on existing width

### 6.3.6 Channel Volumes

In summary, the channel volumes to be excavated for each SHEP depth alternative are summarized in **Table 6.3.6-1** and **6.3.6-2**. These quantities are based on the design template for each depth alternative and represent new work material only including the passing lanes and Kings Island Turning Basin.

**Table 6.3.6-1: New Work Inner Harbor Dredging Volumes**

| Station                        | 44 ft Project (cy) | 45 ft Project (cy) | 46 ft Project (cy) | 47 ft Project (cy) | 48 ft Project (cy) |
|--------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| 0+000 to 4+000                 | 101,482            | 166,705            | 235,626            | 305,674            | 375,403            |
| 4+000 to 6+375                 | 48,128             | 87,346             | 130,559            | 174,073            | 217,263            |
| 6+375 to 30+000 <sup>A</sup>   | 1,264,730          | 1,756,993          | 2,258,262          | 2,759,203          | 3,259,272          |
| 30+000 to 45+000               | 684,583            | 1,052,928          | 1,426,462          | 1,802,866          | 2,181,609          |
| 45+000 to 51+000               | 324,752            | 508,740            | 699,013            | 892,307            | 1,088,128          |
| 51+000 to 57+000 <sup>B</sup>  | 652,793            | 801,504            | 951,201            | 1,101,114          | 1,251,494          |
| 57+000 to 67+000 <sup>C</sup>  | 588,884            | 807,450            | 1,026,002          | 1,244,681          | 1,463,393          |
| 67+000 to 80+125               | 444,210            | 691,727            | 944,611            | 1,196,291          | 1,446,786          |
| 80+125 to 90+000               | 380,724            | 570,368            | 759,169            | 946,436            | 1,132,066          |
| 90+000 to 103+000 <sup>D</sup> | 1,438,457          | 1,803,823          | 2,169,594          | 2,533,434          | 2,895,175          |
| Total                          | 5,928,743          | 8,247,584          | 10,600,499         | 12,956,079         | 15,310,589         |

*A – Includes Long Island Meeting Area, Station 14+000 to 22+000*

*B – Includes Oglethorpe Meeting Area, Station 55+000 to 57+000*

*C – Includes Oglethorpe Meeting Area, Station 57+000 to 59+000*

*D – Includes Kings Island Turning Basin*

**Table 6.3.6-2: New Work Entrance Channel Dredging Volumes**

| Station             | 44 ft Project (cy) | 45 ft Project (cy) | 46 ft Project (cy) | 47 ft Project (cy) | 48 ft Project (cy) |
|---------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| -98+600 to -57+000* | 1,667,123          | 2,242,371          | 2,925,432          | 3,736,308          | 4,613,909          |
| -57+000 to -53+500  | 156,623            | 235,127            | 313,391            | 391,437            | 469,252            |
| -53+500 to -40+000  | 646,796            | 975,843            | 1,304,385          | 1,632,346          | 1,959,186          |
| -40+000 to -30+000  | 505,693            | 771,105            | 1,038,620          | 1,305,921          | 1,573,800          |
| -30+000 to -20+000  | 529,910            | 801,974            | 1,076,638          | 1,352,115          | 1,628,379          |
| -20+000 to -10+000  | 473,047            | 746,614            | 1,028,399          | 1,311,222          | 1,594,871          |
| -10+000 to 0+000    | 346,997            | 532,621            | 723,394            | 917,064            | 1,110,713          |
| Total               | 4,326,189          | 6,305,655          | 8,410,259          | 10,646,413         | 12,950,110         |

*\*Station -98+600 is the extended channel stationing for the 48 ft project depth. Channel stationing for the 47 ft project depth across the ocean bar terminates at Station -97+680.*



## 6.4 CHANNEL SIDE SLOPE STABILITIES

### 6.4.1 Introduction

A report prepared by USACE titled *Savannah Harbor Expansion Bank Stability Report* is included in the Engineering Investigations Supplemental Materials. The report includes computations, sketches, analyses, and preliminary drawings regarding channel side slopes. Computations are based on drilling data, test results from soil samples taken at drilling locations, the latest survey data as of 2005, hill survey data as requested for specific locations, observation/review of channel side slopes resulting from previous harbor widening and deepening projects, and other information from previous dredging projects regarding channel side slope performance. Observations and survey measurements made from about 1816 to 2003 in Savannah Harbor establish that the ship channel or prism side slope averages 1 vertical to 3 horizontal for the harbor channel and about 1 vertical to 5 horizontal for the jetties and bar channel reaches. Variations have been noted at isolated locations that have either flatter or steeper side slopes that generally are the result of past efforts at filling older drainage features or other man-made modifications. The variations noted occur well beyond the channel sailing prism and do not appear to impact or influence vessel movements.

### 6.4.2 General

Addressed during analyses are the known locations or reaches of possible problem areas regarding channel side slopes, sloughing of materials, and/or real estate acquisition requirements. Each is discussed separately in the *Savannah Harbor Bank Stability Report* dated 2003. The results of this report were updated in June 2010 to incorporate changes in channel alignment, wideners and meeting areas recommended by the ship simulator study. Areas that are not specifically addressed were also reviewed in detail using the proposed channel geometries and the most recent survey/sounding information. Review of these areas indicates the proposed deepening/expansion will not have a direct effect on real estate above mean low water (MLW) nor interfere with structures located on the river's edge.

Inspections were performed as a part of obtaining riverbank and structural information within the limits of this project in 2001 and again in 2003. The inspections document the condition of structures on or along the shoreline within the limits of the project. A copy of the reports, photographs, and descriptions are included as Appendix to the *Bank Stability Report*.

Several hundred borings have been drilled within and adjacent to the Savannah Harbor. The majority of these borings were drilled along the north side of the channel for the Savannah Harbor Widening and the Savannah Harbor Deepening projects, then supplemented with additional borings for the Expansion. These borings were drilled to obtain information necessary for evaluating the in-situ materials within specific areas of the channel for harbor modification projects. The majority of the borings were water-borne. The land-based borings were completed to identify soil materials within the channel side slopes to help determine the most probable channel side slopes resulting for each proposed harbor modification. The investigations have used a variety of methods to obtain subsurface data, including Vibracore, splitspooing, coring, cone penetration tests, and other methods. Standard penetration sampling using a split-barrel sampler was the method most often used. Using this method, a 1-3/8 inch inner diameter standard split barrel sampler was driven through the material using a 140-pound hammer with a 30-inch fall. The sampler was retrieved and the material was described in accordance with the Unified Soil Classification System.



### 6.4.3 Analyses Overview

Slope analyses for selected locations were performed using the Modified Slope Stability Package with Kansas City Analysis (DGSLOPE) and the computer program UTEXAS3. Both programs were used for either original analysis and for the checking and verification of results. Final input data sets, illustrations, cross-sections, slip circles and/or wedge sections, and the results obtained are provided in the Bank Stability Report. The project team adopted a method of deepening that calls for maintaining the existing side slopes to the proposed deepened elevations thus negating the need to acquire real estate throughout the harbor. Exceptions occur at planned meeting areas and curve wideners.

### 6.4.4 Summary

The planned wideners in the area of Channel Station 102+000 and Kings Island Turning Basin expansion were analyzed with regard to most probable slopes and the resultant requirement for real estate acquisition. Each was evaluated and acreage determined assuming an acquisition need measured from the zero (0) mean low water elevation and again from the plus eight (+8) mean low water elevation. The widener proposed north of Kings Island Turning Basin requires approximately 3.9 acres above elevation zero or approximately 1.1 acres above elevation +8, described as “taking” or acquisition. Kings Island Turning Basin requires approximately 5.0 acres above elevation zero and approximately 4.4 acres above elevation +8 described as “taking” or acquisition. An additional 30-foot wide temporary right-of-way should also be obtained for use during construction. The areas are shown in **Figure 6.4.4-1**.

The area between Channel Stations 95+700 to 97+000, north side adjacent to Confinement Area 2A, is included because the existing side slopes appear to be in a constant state of failure. However, in theory, no real estate will be required. In total, there are four (4) areas identified for real estate acquisition, each addressed in detail within the *Bank Stability Report* and outlined below in **Table 6.4.4-1** and the Figures that follow, **Figure 6.4.4-1** to **Figure 6.4.4-3**. There are no other known areas of concern with respect to the channel prism and the stability thereof.

**Table 6.4.4-1: Areas Identified for Real Estate Acquisition**

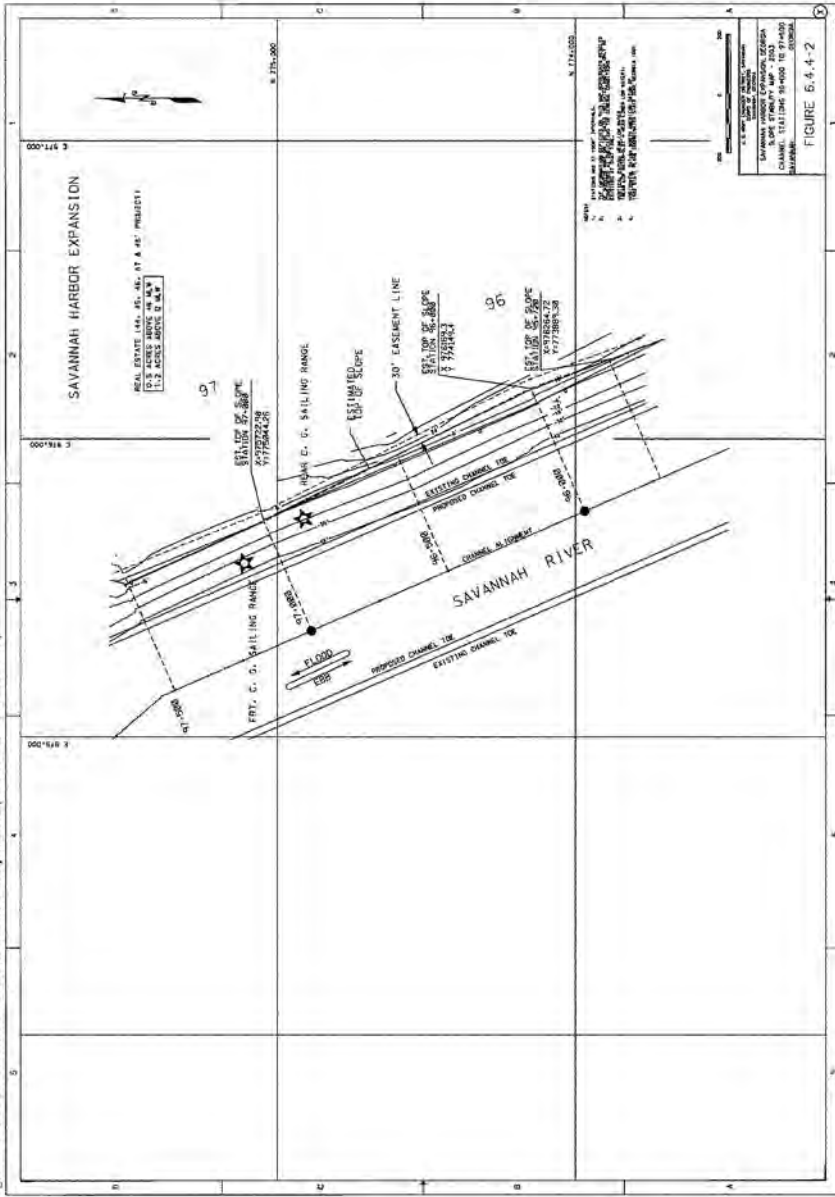
| Channel Location |         | 44 ft Project Alternative         |                                   | 45, 46, 47 and 48 ft Project Alternatives |                                   | Relating Figure |
|------------------|---------|-----------------------------------|-----------------------------------|-------------------------------------------|-----------------------------------|-----------------|
| From             | To      | Acquisition Above 0 ft MLLW Acres | Acquisition Above 8 ft MLLW Acres | Acquisition Above 0 ft MLLW Acres         | Acquisition Above 8 ft MLLW Acres |                 |
| 101+200          | 102+500 | 3.7                               | 0.9                               | 3.9                                       | 1.1                               | 6.4.4-1         |
| 98+200           | 100+500 | 4.8                               | 4.2                               | 5.0                                       | 4.4                               |                 |
| 96+000           | 97+000  | 1.2                               | 0.5                               | 1.2                                       | 0.5                               | 6.4.4-2         |
| 86+000           | 88+500  | 1.9                               | 0.4                               | 2.1                                       | 0.6                               | 6.4.4-3         |







Figure 6.4.4-2: Areas Identified for Real Estate Acquisition (Station 96+000 – 97+000)











## 7.0 HYDRODYNAMIC MODELING

The three-dimensional hydrodynamic model Environmental Fluid Dynamics Computer Code (EFDC) and the Water Quality Analysis Simulation Package (WASP) models were enhanced and calibrated for application to the SHEP. A summary of the model development and calibration is contained in the following sections of this Appendix, greater detail can be found in a report prepared by Tetra Tech titled *Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project* dated January 2006 which is included in the Engineering Investigations Supplemental Materials.

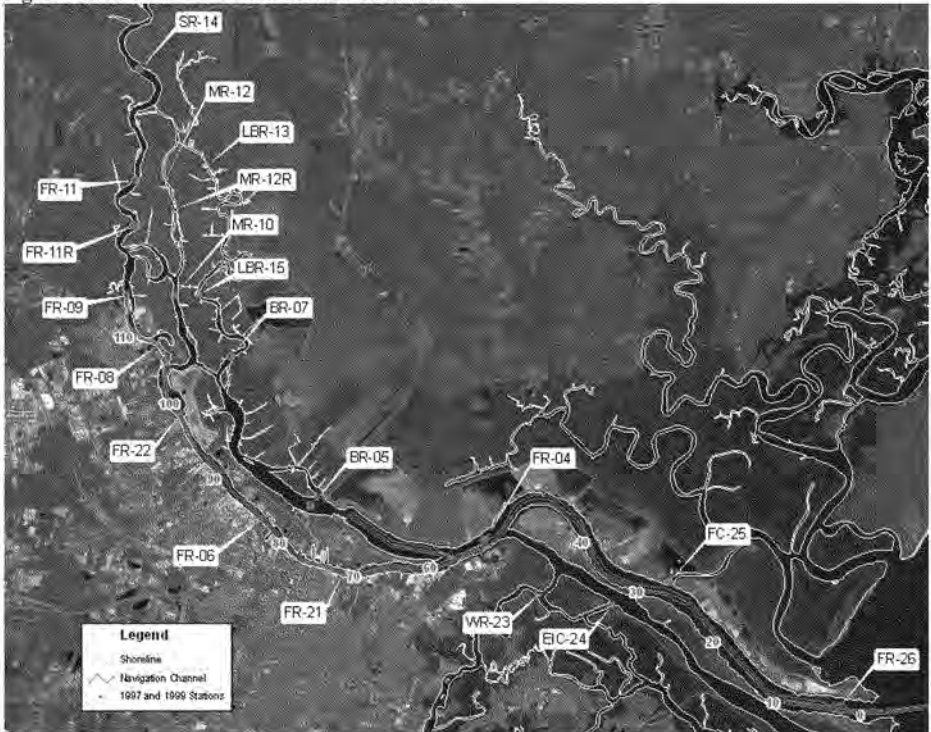
For SHEP, modification and calibration of the EFDC and WASP models was necessary to have a means to (1) predict and quantify impacts to the estuary and (2) to develop mitigation features and plans that are scientifically sound and acceptable to all of the Federal Agencies involved in SHEP. The SHEP model applications have been designed to meet the expectations of the Modeling Technical Review Group (MTRG) consisting of federal and state agencies. For documentation from the agencies stating support of the models developed for SHEP, see the document titled *Correspondence between USACE & Federal/State Agencies Regarding Hydrodynamic & Water Quality Model Acceptability* which is included in the Engineering Investigations Supplemental Materials.

The model code, modeling results, in both time series and statistical formats, and a database, which contains model comparison data were made available for peer review in addition to federal and state agency review prior to use of the model for SHEP impact determination and mitigation design. Comments and responses to the peer review and the model team review can be found in the 2006 report prepared by Tetra Tech.

In addition to the model review, Kinetic Analysis Corporation performed an uncertainty analysis of the SHEP model. The analysis took approximately 2 months and upon review of the results, Tetra Tech agreed that indeed there is uncertainty in the model and the uncertainty predicted was reasonable. Furthermore, having an uncertainty prediction with a mechanistic model is valid because it shows a range of conditions expected. Results of the uncertainty analysis are also included in the 2006 report prepared by Tetra Tech.

### 7.1 DATA COLLECTION

In preparation for this modeling, an extensive data collection effort took place during the summers of 1997 and 1999. Funded and directed by the GPA, the data collection was carried out by ATM, Inc. See **Figure 7.1-1** for location map. Data was collected during summer months to capture the critical period for dissolved oxygen (D.O.). In addition to D.O., salinity, temperature, and water level data were also collected at these sites. The US Fish and Wildlife Service, at the same time, began a study and collection of data of porewater salinity and associated plant species growth in the wetland areas.

**Figure 7.1-1: Data Collection Station Locations**

## 7.2 MODEL SELECTION

The Modeling Technical Review Group was setup by GPA in the late 1990s to review the model for the deepening project and determine its viability for use.

The MTRG consisted of technical modelers from federal and state agencies. Federal agencies involved included the USEPA, USF&W, USGS, NMFS (National Marine Fisheries) and the Corps of Engineers. State agencies involved included Georgia EPD and South Carolina DHEC.

The MTRG determined a previous model, developed by consultants to GPA, was not defensible for salinity intrusion and water quality effects. The model had difficulties with the vertical mixing scheme and was not accepted by the Federal agencies reviewing the project. In response, the agencies prepared a Federal Expectations Document in 2003 that described:

- the resources of primary concern in the estuary,
- the locations and conditions under which project impacts should be evaluated for those resources,
- the modeling approach to be taken,

- the statistical analyses to be performed to document the model's performance,
- the evaluation criteria.

The Expectations Document stated that its listed criteria were to be viewed as performance goals to which model predictions would be compared and evaluated for strengths and weaknesses and by which an understanding of their uncertainties may be developed. The stated criteria would not be used individually (by station and parameter) for a "pass/fail" evaluation of the model calibration and/or any post-processing routine. The Federal Expectations Document titled, *Savannah Harbor Data Analysis & Modeling Expectations of Federal Agencies*, is included in the Engineering Investigations Supplemental Materials.

The models used to assess the environmental impacts of the SHEP are:

Environmental Fluid Dynamics Computer Code (EFDC) – EFDC was selected to perform the hydrodynamic simulations because it meets the agencies expectations and project study goals. Consideration of the hydrodynamic/water quality linkage was also a concern during model selection. The EFDC model is a part of the EPA's TMDL Modeling Toolbox due to its application in many TMDL-type projects. As such, the code has been peer reviewed and tested and has been freely distributed for public use. The EFDC model is nonproprietary and publicly available through USEPA Region 4 and USEPA Office of Research and Development. EFDC was developed by Dr. John Hamrick and is currently supported by Tetra Tech.

The EFDC model comprises an advanced three-dimensional surface water modeling system for hydrodynamic and reactive transport simulations of rivers, lakes, reservoirs, wetland systems, estuaries and the coastal ocean. EFDC is a multifunctional, surface water modeling system, which includes hydrodynamic, sediment-contaminant, and eutrophication components. The model's hydrodynamic component is based on the three-dimensional shallow water equations and includes dynamically coupled salinity and temperature transport. The model also includes representation of hydraulic structures for controlled flow systems.

Water Quality Analysis Simulation Program (WASP) – WASP Version 7.0 was selected for the water quality model development. WASP7 was released by EPA on April 27, 2005 and is part of the TMDL Modeling Toolbox. WASP is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading and boundary exchange are represented in the program. The water quality model incorporates normal oxygen dynamics, including reaeration, sediment oxygen demand, carbonaceous Biochemical Oxygen Demand and uptake, and Nitrogenous Biochemical Oxygen Demand and uptake.

The EFDC model provides ocean flow and tidal dynamics, upstream flow, 3D model cell structure and volumes, cell volumes, and transport and salinity and temperature. The hydrodynamic modeling information is incorporated into the WASP model through the hydrodynamic linkage file. Both of these models are certified for use by the US Army Corps of Engineers, in accordance with the Enterprise Standard (ES)-08101, *Software Validation for the Hydrology, Hydraulics, and Coastal Community of Practice*.

## 7.3 MODEL DEVELOPMENT & CALIBRATION

### 7.3.1 Model Grid Development

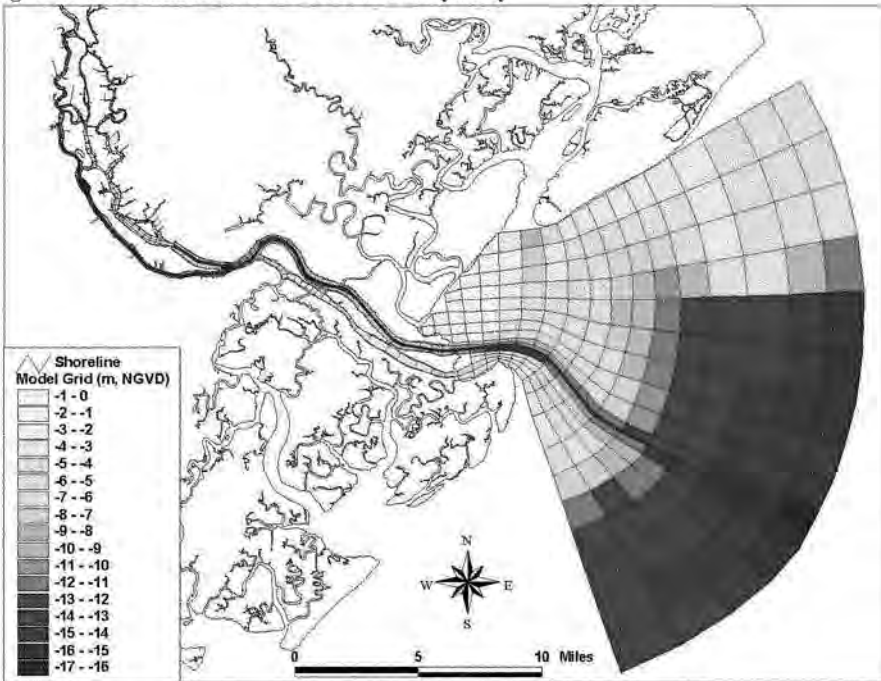
The model grid for both EFDC and WASP was enhanced from modeling previously developed and performed by ATM. The enhanced models were developed in consideration of the following efforts:

- US Army Corps of Engineers Savannah Harbor Ecosystem Restoration Project,
- Finalization of the EPA Region 4 Dissolved Oxygen TMDL,
- The States of Georgia and South Carolina issuing National Pollutant Discharge Elimination System (NPDES) permits.

EPA Region 4 issued the draft dissolved oxygen TMDL on August 30, 2004, and the public notice/comment period ended on January 31, 2005. The TMDL models were run on a coarse grid in which the EFDC hydrodynamic and the WASP water quality models were applied. The coarse grid, now referred to as the TMDL grid, met the following objectives defined by EPA:

- To represent accurately the key hydrodynamic processes of transport in the estuary,
- To utilize a model that is public domain and has been peer reviewed,
- To deliver the model to the federal agencies involved in the TMDL process,
- To run the model for multiple hydrologic periods and evaluate point and nonpoint sources, and
- To complete the effort in a timely manner in order to meet the project schedule.

The effort to develop an enhanced grid was initiated on September 29, 2004 to improve the representation of the estuary system and navigation channel. The enhanced grid is designed to allow evaluation of various scenarios such as deepening of the navigation channel and physical modifications to certain cuts and channels in the river and estuary. The major enhancements included developing a finer model grid, updating the bathymetric data used by the model, and an alternate approach for the model calculation of the river-marsh interactions. The same models, EFDC and WASP, were used on the TMDL grid and the enhanced grid. **Figure 7.3.1-1** shows the enhanced model grid and bathymetry.

**Figure 7.3.1-1: Enhanced Model Grid and Bathymetry**

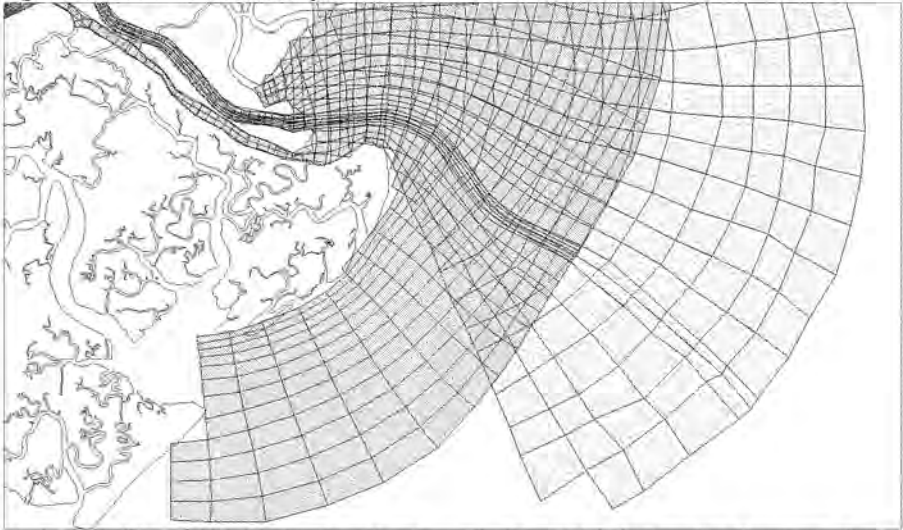
Specifically, the model grid was enhanced to include more cells in the navigation channel. There are now 931 horizontal cells that extend upstream to Clyo, Georgia (~61 miles from Fort Pulaski) and downstream to the Atlantic Ocean (~17 miles offshore from Fort Pulaski). Including the marsh cells adjacent to the river system, there are 947 total cells. The man-made connections, such as McCoys Cut, Rifle Cut, Drakies Cut, New Cut as closed, and the sill of the tidegate, were also included in the enhancement.

The original EFDC model grid developed for EPA Region 4 for the TMDL extended from the mouth of the river down the southern shoreline (See **Figure 7.3.1-2**, pink). This grid configuration had difficulty mimicking the water surface elevations in the area because the tidal forcing conditions were “bouncing” off the shoreline or back of the grid. Having tides as forcing functions on the south and east sides of the grid would create instabilities in the model.

This was overcome by reshaping the grid and allowing the reflective wave to propagate out of the model domain along the shoreline by incorporating externally specified radiation stresses. Alternatively, the shoreline boundary could have been extended further south to include the additional tidal creeks in the Ossabaw Sound, but there was no value in enlarging the model grid in this way. The purpose of the grid boundary conditions and termination 17 miles offshore was to propagate a tide and salinity condition to match the observed measurements at the mouth of the Savannah River. To be

clear, the model does not have an open boundary condition on the southern end of the EFDC and WASP model grid.

**Figure 7.3.1-2: Model Grid Comparison**



*Original model grid extending southward is shown in pink and the TMDL grid is shown in yellow. The SHEP model was based on enhancements to the TMDL grid.*

Additionally, there are shelf circulation patterns that are not captured or simulated by the SHEP model grid despite the tidal boundary being 17 miles offshore which affect the salinity regime. It is recognized that there are seasonal variations in continental shelf salinity due to Savannah River freshwater discharge. This was documented in research by J. O. Blanton and others, published in the *Journal of Geophysical Research*, 88(C8):4705-4718. This topic was presented to the MTRG and the group agreed that the tide and salinity propagation at the mouth was most important and that the seaward boundary, 17 miles offshore, is appropriate for the goals set by the MTRG for the SHEP model. The logic for this decision is that, for future with-project salinity projections, the MTRG wanted to be sure that modeled changes to salinity were due to the proposed deepening project and mitigation features, and not due to seasonal variation in the boundary condition.

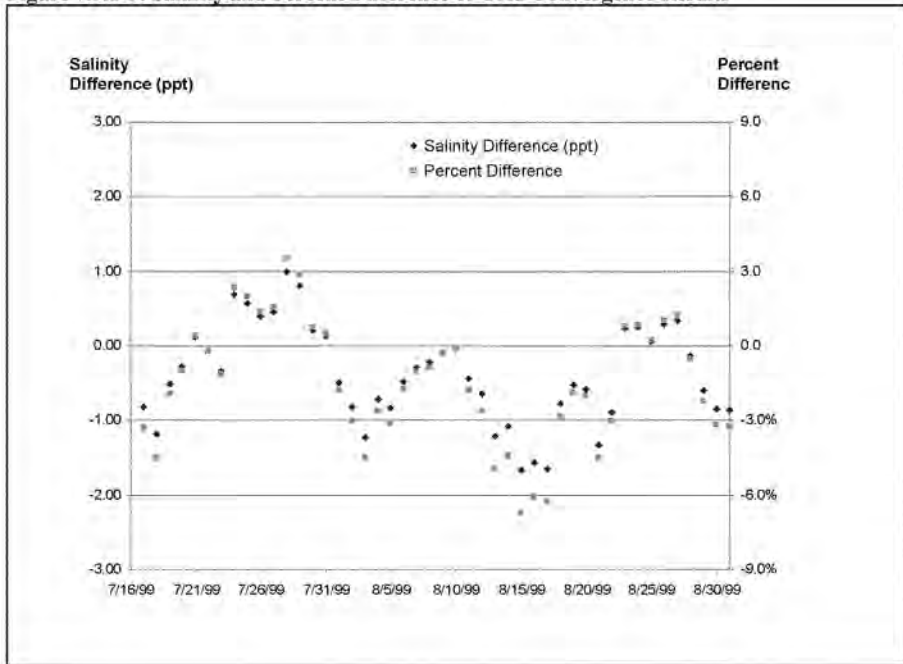
Grid convergence and orthogonality were key considerations for developing a defensible model for SHEP application. Orthogonality is balanced between model grid cell size and model run time. The final grid is representative of this balance, sacrificing some orthogonality to achieve the overall goals of a representative model with workable model run times.

Quantification of the convergence grid test results has been performed and is presented in the **Table 7.3.1-1**. Model spin up has been excluded from these statistics.

**Table 7.3.1-1: Quantification of the Convergence Grid Test Results**

| Site  | Layer   | Enhanced Grid Average Salinity (ppt) | Convergence Grid Average Salinity (ppt) | Average Difference (ppt) | Average Percent Difference |
|-------|---------|--------------------------------------|-----------------------------------------|--------------------------|----------------------------|
| FR-09 | Bottom  | 27.27                                | 26.83                                   | -0.43                    | -1.6%                      |
| FR-09 | Surface | 6.78                                 | 5.69                                    | -1.09                    | -16.2%                     |
| SR-17 | Bottom  | 0.005                                | 0.006                                   | 0.001                    | 21.9%                      |

**Figure 7.3.1-3** shows the daily average bottom salinity difference and percent difference at data collection Station FR-09 (see **Figure 7.1-1** for FR-09 location). The figure shows no consistent trend of difference (no divergence with time). The minor difference in system response for each grid may depend more on hydrologic or tidal conditions.

**Figure 7.3.1-3: Salinity and Percent Difference of Grid Convergence Results**



### 7.3.2 Bathymetry

The bathymetry data was obtained from several sources because there is not one continuous bathymetry dataset that encompasses the entire system. To simply prescribe a channel design template onto the model grid does not adequately reflect the continuous sedimentation and dredging that is ongoing in the harbor. The sources are as follows:

- USACE Annual Surveys (1999 and 2002)
- USGS SNWR (2004) for the Back, Middle and Little Back Rivers
- USACE Upstream of I-95 (1999)
- NOAA Surveys (1980s) for the offshore non-channel and south channel areas.

By using the bathymetry datasets described above, the SHEP model includes advanced maintenance and overdredge depths for all model scenarios. The model accounts for the overdredge volume in the navigation channel by assuming the overdredge is the same in the 42-foot channel (existing conditions) as it would be in any dredged channel depth.

Furthermore, since advance maintenance is proposed to be essentially the same for deepened conditions as for existing conditions, then we subtracted 2 feet for the 44-foot depth, 3 feet for the 45-foot depth, 4 feet for the 46-foot depth, 5 feet for the 47-foot depth, and 6 feet for the 48-foot depth bathymetry inputs. All depths reference Mean Lower Low Water (MLLW). The reality in the model is that the 48-foot depth is closer to 52 feet which includes the additional depths due to advance maintenance and overdredge.

**Figures 7.3.2-1 through 7.3.2-3** illustrate how the bathymetry is described in the model. **Figure 7.3.2-1** shows actual measured data from the USACE 1999 Annual Survey. **Figure 7.3.2-2** shows the cross-section in the model at the same location and **Figure 7.3.2-3** represents the modeled 6-foot deepened conditions.



Figure 7.3.2-1: Existing Depth from 1999 Annual Survey at Station 96+000

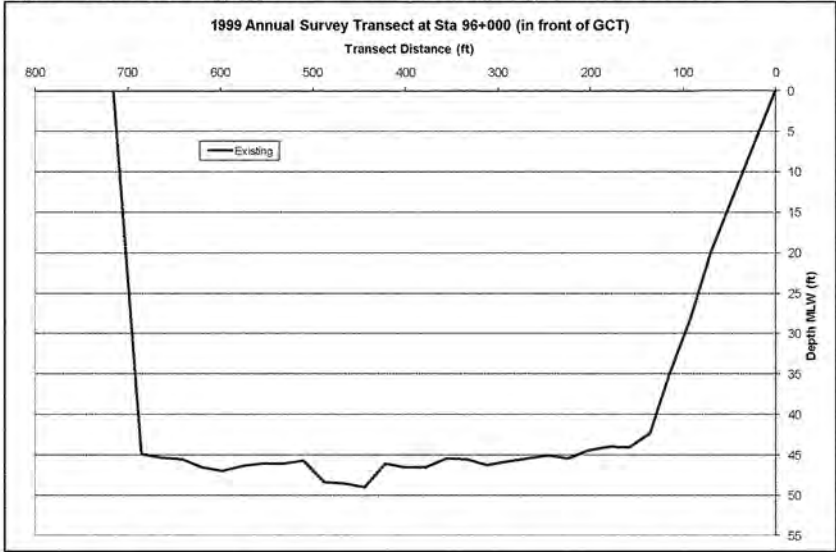
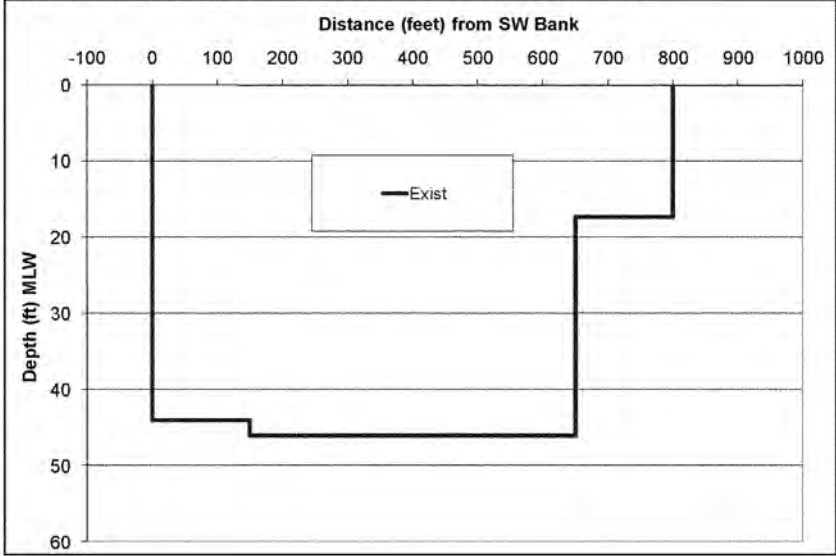
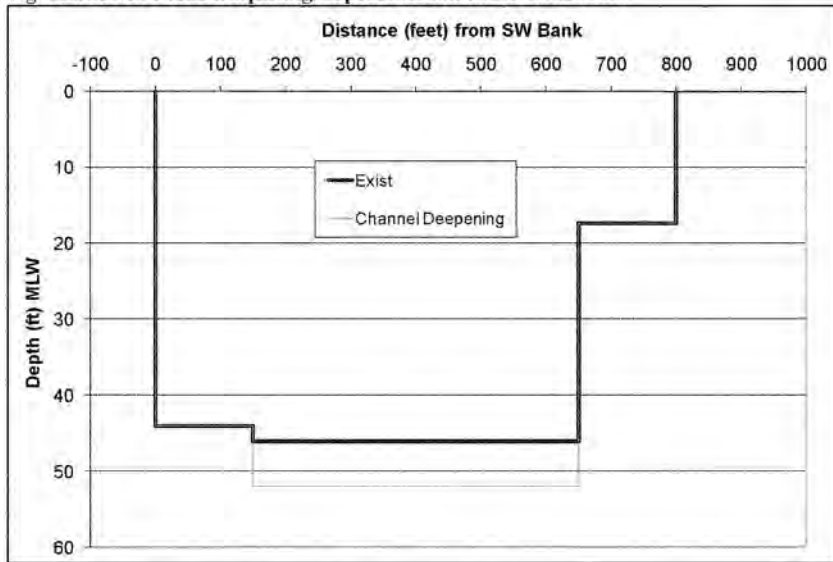


Figure 7.3.2-2: Existing Conditions Represented in the EFDC model



**Figure 7.3.2-3: 6-foot Deepening Represented in the EFDC model**

### 7.3.3 Water Quality Modeling Parameters

#### 7.3.3.1 Nutrient Flux and Sediment Oxygen Demand

Ammonia fluxes were insignificant and not included in the model. Based on the sediment oxygen demand (SOD) and nutrient flux measurements collected by EPA SEDS in 1999, the ammonia fluxes measured were close to zero due to the amount of scour and movement in bed materials in the navigation channel. Data sources of for SOD and nutrient fluxes include:

- *Oxygen Diffusion Study and Sediment Oxygen Demand Study*, Savannah River, Savannah, Georgia (August 2-14, 1999, EPA Science and Ecosystem Support Division, Ecological Assessment Branch, Athens, Georgia
- *Savannah River Classification Study - October 1985*, Sediment Oxygen Demand Surveys, Summary, 1985, GAEPD, Atlanta Ga.
- *Application of CE-QUAL-W2 to the Savannah River Estuary*, Technical Report EL-87-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS (Hall, Ross W., 1987)

The ammonia data in the vicinity of point sources is higher than background, but everywhere else in the system, the ammonia concentrations are near detection limits at 0.02 to 0.03 mg/L. The MTRG analyzed the SOD and flux data and concluded ammonia fluxes were not significant to include in the WASP model. However, a spatial representation of SOD for the WASP model was included.

### 7.3.3.2 Algal Activity

The MTRG decided in 2005 that excluding algae, and therefore not using the full eutrophication model in WASP, was appropriate for SHEP. There is limited to no chlorophyll-a data measured in the harbor. Through data analysis and model simulations, it was determined that algal activity effects on dissolved oxygen are negligible.

As stated in the model calibration report prepared by Tetra Tech titled *Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project*, "Since there is limited algal activity or primary production in the harbor, nutrients were determined not to be a significant issue by EPA Region 4 and were not included in the water quality modeling scenarios. The water quality model incorporated normal oxygen dynamics, including reaeration, sediment oxygen demand (SOD), carbonaceous Biochemical Oxygen Demand (CBOD) and uptake, and Nitrogenous Biochemical Oxygen Demand (NBOD) and uptake."

The EPA Science and Ecosystem Support Division (SESD) conducted a light-dark bottle algal study and showed no algal growth in the system due to color and fast flushing times. With the limited chlorophyll-a data, there were low levels in the surface. Temporary and sporadic elevated levels were found in bottom layers due to intrusion from the ocean.

The EPA SESD field crews had great difficulty obtaining nutrient flux measurements in the harbor, but  $\text{NH}_3$  fluxes are not expected in the harbor because of the high velocity on the bottom. Also, the harbor is relatively insensitive to ammonia because of low decay rates due to high ocean water dilution. That said, the river model was sensitive to ammonia but again no fluxes measured or expected due to high velocities.

In addition, the dissolved oxygen signal closely matches the tidal signal. The reason being because the tidal signal is strong and the reaeration (due to turbulence and wind) cause the dissolved oxygen to rise and fall. Temperature plays an important role along with the BOD loading, low oxygen in the marshes, and SOD. Therefore, the algal growth effects due to nutrients is limited or very small compared to velocity, turbulence, wind, BOD loads, SOD, and marshes.

### 7.3.4 Calibration

The model calibration details can be found in the report prepared by Tetra Tech titled *Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project* dated January 2006 which is included in the Engineering Investigations Supplemental Materials. The model development and calibration report includes both the hydrodynamic and water quality modeling results along with calibration and confirmation periods. The calibration of the models was performed to the summer of 1999 data, the period with the most comprehensive dataset. The confirmation of the model was performed to the summer of 1997 data and the USGS long-term data from January 1, 1997 through December 31, 2003.

The model calibration had two primary goals: (Task A) to modify and recalibrate the EFDC model and (Task B) to re-evaluate the calibration of the WASP water quality model, if needed, because of revisions to the EFDC hydrodynamic model. The objectives of Task A were to modify the EFDC model to improve the grid resolution, tidal-marsh interaction, and boundary conditions in response to issues raised during the SHEP federal and state technical review of the initial calibration report on the

EFDC portion of the TMDL grid. The objective of Task B was to re-evaluate the calibration of the WASP model for use in predicting dissolved oxygen in the harbor and use in future SHE Project alternatives. The USACE Savannah District along with the other Federal agencies believed that modifications to the TMDL grid of the EFDC and WASP models might also enhance the TMDL Models' capabilities.

Calibration methodology for the EFDC model included graphical time series comparisons (qualitative) and statistical calculations (quantitative). The calibration was also parameter specific including water surface elevation, currents, flow, temperature and salinity. The order in which the hydrodynamic model is calibrated is performed to address issues such as bathymetry, friction, tidal volume, cross-sectional area, and heat budget before salinity is calibrated. Salinity is the predominant signal in the model to ensure that mass is being moved horizontally and vertically with the appropriate timing and direction.

Model calibration was further improved through coordination with scientists at the Skidaway Institute of Oceanography in Savannah, GA and utilization of a time series boundary condition of salinity based on the SABSOON data (Station R2) which captured the phenomenon of high river flow events producing lower salinity at the boundary of the model. South Atlantic Bight Synoptic Offshore Observational Network (SABSOON) is a real-time observational network developed on the US Southeastern continental shelf providing a range of oceanographic and meteorological observations on a continuous real-time basis. It was very important to the MTRG to have a defensible boundary that would be consistent for multi-year, multi-scenario applications. The seaward boundary is appropriate for the goals set by the MTRG for the SHEP model.

The calibration salinity boundary was determined to be a best-fit linear function from 32.5 ppt (surface) to 35 ppt (bottom). Datasets available from NOAA for the "World Ocean Atlas" annual means, suggest that regional annual mean value of surface salinity may be in the range 34-36 ppt. For comparison, data from SABSOON site R2 which is located approximately 50 miles offshore from the mouth of the Savannah River indicate mean surface salinity of 36.0 ppt (range 31.5 - 36.5 ppt for the period 1999-2002).

To assess model sensitivity and the possibility of improving the calibration, the EFDC model was run for 35 ppt (surface to bottom) and 36 ppt constant boundary conditions. Results were increased salinity in the lower Front River both at the surface and the bottom. As expected, predicted salinity was increased more at Ft. Pulaski (FR-26) than upstream at sites such as FR-08, for example. Results are shown in **Figures 7.3.4-1** through **7.3.4-3** for FR-26 and FR-08. Increasing the offshore boundary condition for salinity does not improve the calibration.

Figure 7.3.4-1: Salinity Comparisons at FR-26 at the Surface

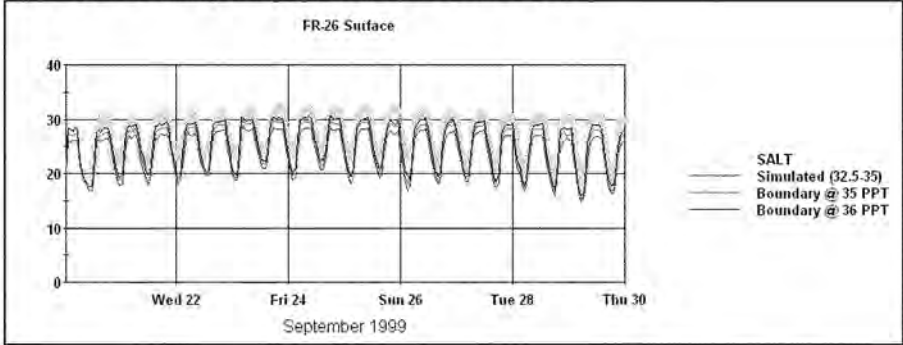


Figure 7.3.4-2: Salinity Comparisons at FR-26 at the Bottom

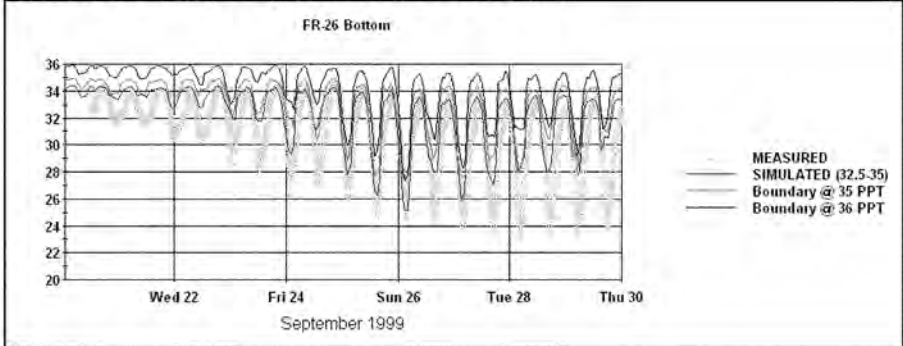
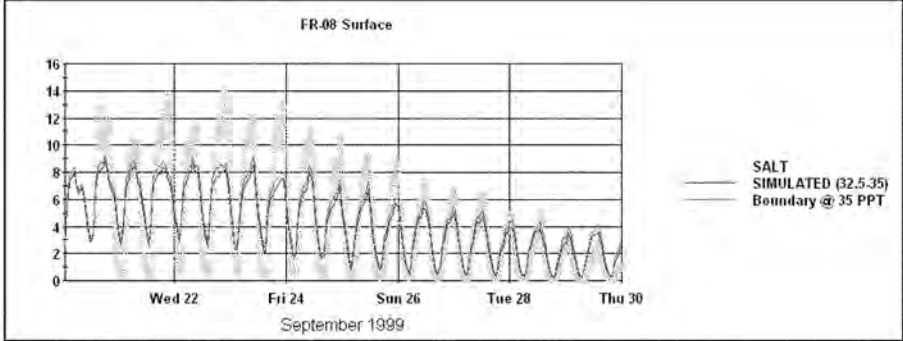


Figure 7.3.4-3: Salinity Comparisons at FR-08 at the Surface



The WASP model calibration was performed using the summer 1999 dataset. The EFDC model was used to provide the model grids, depths, volumes, velocities, and diffusion parameters along with the predicted temperatures and salinities. The main calibration parameters were minor adjustments to SOD and the reaeration scaling factor. The measured values from the data collected during the 1999 summer survey were used for calibration of the WASP model. The data consisted of dissolved oxygen, BOD, ammonia, other nutrients, and chlorophyll-a concentrations. Specifically, for the WASP model calibration, dissolved oxygen, BOD and ammonia were used.

### 7.3.5 Model Grid Comparison

The hydrodynamic and water quality models as developed for use in SHEP impact determination and mitigation development design were determined to be acceptable for this purpose in March 2006 by the MTRG and the state and federal agencies involved in the group including, USEPA, USFWS, GAEPD, and SCDHEC. This set of models is described as enhanced from the previously developed models in the late 1990s by ATM at the direction of GPA.

The enhanced grid is designed to allow evaluation of various scenarios such as deepening of the navigation channel and physical modifications to certain cuts and channels in the river and estuary. The major enhancements included developing a finer model grid, updating the bathymetric data used by the model, and an alternate approach for the model calculation of the river-marsh interactions.

Over the course of time, the enhanced grid came to be known as the Sigma model which is a terrain following vertical grid which allows the layers to compress and expand (stretch) with changing water surface elevation. During 2007, EPA Region 4 determined a need to convert the Sigma model grid (ie, the enhanced model used for SHEP purposes) to a Z-Grid. The Z-Grid model allows for variations in the number of vertical layers throughout the model domain. The Sigma Grid has six vertical layers with widely varying layer depths and the Z-Grid model has five vertical layers in the navigation channel and one vertical layer in the Middle, Back, Little Back and Upper Savannah Rivers. A benefit of the Z-Grid is that there are fewer computations over the same model domain which reduces run times significantly. When numerous runs are required, the Z-Grid can offer substantial time savings. Additionally, the Z-Grid was later updated with new Middle River and Back River bathymetry and recalibrated to 2009 USGS velocity and flow data. This newer version of the model, known now as the Z-Grid model, was further enhanced in 2010 to be used for SHEP impacts to chlorides on Abercom Creek.

The versions of the model were compared and results from the analysis can be found in the report titled *Model Comparison Report in support of the Savannah Harbor Expansion Project* dated July 2011 and included in the Engineering Investigations Supplemental Materials. The report, prepared by Tetra Tech, documents the differences between the two models and ultimately recommends continuing to use the Sigma model for the impacts determination and mitigation development for harbor deepening.

### 7.4 IMPACTS DETERMINATION

In support of the Environmental Impact Statement (EIS), the hydrodynamic and water quality models were used to evaluate the impacts from deepening the navigation channel to the environment and natural resources within the Savannah River Estuary. The Interagency Coordination Team developed parameters and run scenarios for use in the models as a way to characterize and determine impacts. The Interagency Coordination Team is comprised of biologists, physical scientists, resource specialists,

and engineers from both federal and state agencies that are charged with reviewing the details of the SHEP and giving environmental clearances. The team developed four basic environment/resource categories that were evaluated:

- Fishery Habitat
- Water Quality and Dissolved Oxygen
- Wetlands
- Chlorides

Each of the four categories has several run scenarios and parameter evaluation requirements used to determine impacts for that specific category. Rarely did the run scenarios overlap between categories. The result is numerous data plots, charts, figures and tables that show the results of the model run and quantitatively describe the impacts. The output is cumbersome and highly detailed and was purposefully done in an attempt to identify any and all impacts on habitat and natural resources under a wide variety of conditions in support of the needs of the Interagency Coordination Team.

### 7.4.1 Post Processor

To aid in quantifying the impacts, a program was developed by Tetra Tech that reads the complex model output from either the hydrodynamic (EFDC) or water quality (WASP) model, which are in BMD file formats, then analyzes and performs statistics and produces results that are more easily interpreted. The Post Processor has several modules that can calculate averages, percentiles, maximums, and minimums for a variety of parameters with speed and accuracy. The same observations and calculations could have been made manually, but with the size of the model grid and the vast amount of output generated by the model, that task would have been daunting. The Post Processor has proven to be an invaluable tool in analyzing such large datasets.

Outside of the Corps' acceptance and use of the Post Processor for the Expansion Project, the program has also been used by Tetra Tech and EPA Region 4 to determine TMDL scenarios for meeting water quality standards. Both Georgia EPD and South Carolina DHEC are also using the tool to compare and develop water quality standards for the harbor. In addition to Tetra Tech's internal peer review of the Post Processor, there have been several other modelers/engineers with federal and state agencies that have peer reviewed the tool through their use and application.

### 7.4.2 Fishery Habitat Modeling

The fishery habitat modeling required model runs to be developed around critical habitat times for various fish species and life cycle stages. Specifically, the species and life stages identified by the Interagency Coordination Team are:

- American Shad
- Striped Bass (eggs, larvae, and spawning)
- Shortnose sturgeon (juveniles and adults)
- Southern Flounder

Each model run for fishery habitat was one month in duration, plus 30 days for model-spin up, during the outlined critical habitat periods. Freshwater flow conditions at the upstream boundary for each run were based on long term percentiles at the USGS stream gage near Clio, GA. Many species were

evaluated for low, average, and high water flow conditions. Parameters evaluated included, salinity, DO, and velocity at various depths over the water column. All parameters, model run scenarios and habitat suitability criteria were developed by the Interagency Coordination Team. See **Table 7.4.2-1** for details.

#### 7.4.2.1 Findings

Impacts determination for fishery habitat required both the EFDC model and WASP model runs, EFDC to predict hydrodynamics and salinity and WASP to predict dissolved oxygen. To aid in evaluation of the output and determination of habitat suitability, the Post Processor Habitat Analysis Module was utilized. This module takes the model output from the EFDC and WASP models and determines habitat suitability based on criteria outlined for each species and life cycle stage. The results include numerous maps and figures showing areas of suitable and unsuitable habitat for each species and life stage. Details of the fishery habitat impact analysis can be found in the report titled *Habitat Impacts of the Savannah Harbor Expansion Project* which is included in the Engineering Investigations Supplemental Materials. A detailed analysis of the results can be found in the EIS. Tables showing the relative acreages were also developed and a summary can be found in **Tables 7.4.2.1-1 through 7.4.2.1-4**.



**Table 7.4.2-1: Fishery Habitat Suitability Criteria**

| Species & Life Stage          | Freshwater Flow Conditions | Simulation Period | Habitat Criteria                                                                                                                                                                                                                               |
|-------------------------------|----------------------------|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Striped Bass (spawning)       | 20%-tile of Long Term      | April             | Suitable habitat when<br>(1) 90th percentile salinity $\leq$ 1 ppt, and<br>(2) Mean velocity $\geq$ 30 cm/s                                                                                                                                    |
|                               | 50%-tile of Long Term      | April             |                                                                                                                                                                                                                                                |
|                               | 80%-tile of Long Term      | April             |                                                                                                                                                                                                                                                |
| Striped Bass (eggs)           | 20%-tile of Long Term      | April             | Suitable habitat when<br>(1) Mean 50th percentile salinity $\leq$ 9 ppt,<br>(2) Mean velocity $\geq$ 30 cm/s, and<br>(3) 10th percentile D.O. $\geq$ 4.5 mg/l                                                                                  |
|                               | 50%-tile of Long Term      | April             |                                                                                                                                                                                                                                                |
|                               | 80%-tile of Long Term      | April             |                                                                                                                                                                                                                                                |
| Striped Bass (larvae)         | 20%-tile of Long Term      | May               | Suitable habitat when<br>(1) Mean 50th percentile salinity between 3 and 9 ppt, and<br>(2) Mean 10th percentile D.O. $\geq$ 4.5 mg/l                                                                                                           |
|                               | 50%-tile of Long Term      | May               |                                                                                                                                                                                                                                                |
|                               | 80%-tile of Long Term      | May               |                                                                                                                                                                                                                                                |
| Southern Flounder             | 50%-tile of Long Term      | August            | Suitable habitat when<br>DO $\geq$ 4.0 mg/l at 90% exceedance (10th percentile)                                                                                                                                                                |
| American Shad                 | 50%-tile of Long Term      | January           | Suitable habitat when<br>D.O. $\geq$ 4.0 mg/l at 90% exceedance (10th percentile)                                                                                                                                                              |
|                               | 50%-tile of Long Term      | May               |                                                                                                                                                                                                                                                |
|                               | 50%-tile of Long Term      | August            |                                                                                                                                                                                                                                                |
| Shortnose Sturgeon (adult)    | 50%-tile of Long Term      | January           | Suitable habitat when DO<br>$\geq$ 3.5 mg/l at 90% exceedance (10 <sup>th</sup> percentile),<br>$\geq$ 3.0 at 95% (5th percentile), and<br>$\geq$ 2.0 at 99% (1 percentile)<br>Suitable habitat when Max Salinity $\leq$ 25 ppt                |
| Shortnose Sturgeon (adult)    | 50%-tile of Long Term      | August            | Suitable habitat when DO<br>$\geq$ 4.0 mg/l at 90% exceedance (10th percentile),<br>$\geq$ 3.0 at 95% (5th percentile), and<br>$\geq$ 2.0 at 99% (1 percentile)<br>Suitable habitat when Max Salinity $\leq$ 10 ppt                            |
| Shortnose Sturgeon (juvenile) | 50%-tile of Long Term      | January           | Suitable habitat when DO<br>$\geq$ 3.5 mg/l at 90% exceedance (10th percentile),<br>$\geq$ 3.0 at 95% (5th percentile), and<br>$\geq$ 2.0 at 99% (1 percentile)<br>Suitable habitat when 50% exceedance of the Max Salinity is $\leq$ 14.9 ppt |

**Table 7.4.2.1-1: Fishery Impacts – American Shad (Deepening Only)**

|             | May20%flows     |                 | May50%flows      |                 | May80%flows |                 |
|-------------|-----------------|-----------------|------------------|-----------------|-------------|-----------------|
|             | IMPACTS (%)     | IMPACTS (acres) | IMPACTS (%)      | IMPACTS (acres) | IMPACTS (%) | IMPACTS (acres) |
| 44 ft depth | 0.0%            | 0               | 0.0%             | 0               | 0.0%        | 0               |
| 45 ft depth | 0.0%            | 0               | 0.0%             | 0               | 0.0%        | 0               |
| 46 ft depth | 0.0%            | 0               | 0.0%             | 0               | 0.0%        | 0               |
| 47 ft depth | 0.0%            | 0               | 0.0%             | 0               | 0.0%        | 0               |
| 48 ft depth | 0.0%            | 0               | 0.0%             | 0               | 0.0%        | 0               |
|             | January50%flows |                 | August Avg flows |                 |             |                 |
|             | IMPACTS (%)     | IMPACTS (acres) | IMPACTS (%)      | IMPACTS (acres) |             |                 |
| 44 ft depth | 0.0%            | 0               | 0.0%             | 0               |             |                 |
| 45 ft depth | 0.0%            | 0               | 0.0%             | 0               |             |                 |
| 46 ft depth | 0.0%            | 0               | 0.0%             | 0               |             |                 |
| 47 ft depth | 0.0%            | 0               | 0.0%             | 0               |             |                 |
| 48 ft depth | 0.0%            | 0               | 0.0%             | 0               |             |                 |

**Table 7.4.2.1-2a: Fishery Impacts – Striped Bass Eggs (Deepening Only)**

|             | April20%flows |                 | April50%flows |                 | April80%flows |                 |
|-------------|---------------|-----------------|---------------|-----------------|---------------|-----------------|
|             | IMPACTS (%)   | IMPACTS (acres) | IMPACTS (%)   | IMPACTS (acres) | IMPACTS (%)   | IMPACTS (acres) |
| 44 ft depth | -10.4%        | -100            | -9.7%         | -163            | -2.2%         | -50             |
| 45 ft depth | -12.3%        | -118            | -11.2%        | -188            | -4.9%         | -111            |
| 46 ft depth | -14.0%        | -135            | -15.9%        | -266            | -4.8%         | -108            |
| 47 ft depth | -17.8%        | -171            | -20.5%        | -344            | -6.4%         | -144            |
| 48 ft depth | -19.4%        | -187            | -24.5%        | -411            | -7.2%         | -162            |

**Table 7.4.2.1-2b: Fishery Impacts – Striped Bass Larvae (Deepening Only)**

|             | May20%flows |                 | May50%flows |                 | May80%flows |                 |
|-------------|-------------|-----------------|-------------|-----------------|-------------|-----------------|
|             | IMPACTS (%) | IMPACTS (acres) | IMPACTS (%) | IMPACTS (acres) | IMPACTS (%) | IMPACTS (acres) |
| 44 ft depth | 38.0%       | 76              | -13.5%      | -76             | -1.1%       | -11             |
| 45 ft depth | 56.4%       | 113             | -18.6%      | -105            | -7.1%       | -71             |
| 46 ft depth | 99.5%       | 199             | -21.0%      | -119            | -4.8%       | -48             |
| 47 ft depth | 105.8%      | 211             | -13.8%      | -78             | 6.6%        | 66              |
| 48 ft depth | 104.6%      | 209             | -13.8%      | -78             | 6.0%        | 60              |

**Table 7.4.2.1-2c: Fishery Impacts – Striped Bass Spawning (Deepening Only)**

|             | April 20% flows |                 | April 50% flows |                 | April 80% flows |                 |
|-------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|             | IMPACTS (%)     | IMPACTS (acres) | IMPACTS (%)     | IMPACTS (acres) | IMPACTS (%)     | IMPACTS (acres) |
| 44 ft depth | -7.6%           | -49             | -8.0%           | -83             | -6.2%           | -114            |
| 45 ft depth | -10.9%          | -70             | -12.2%          | -127            | -6.6%           | -121            |
| 46 ft depth | -12.7%          | -81             | -13.0%          | -135            | -12.8%          | -236            |
| 47 ft depth | -14.3%          | -91             | -18.1%          | -188            | 14.7%           | 271             |
| 48 ft depth | -16.9%          | -108            | -19.7%          | -205            | -17.3%          | -318            |

**Table 7.4.2.1-3: Fishery Impacts – Shortnose sturgeon (Deepening Only)**

|             | JUVENILES         |                 | ADULTS            |                 |                  |                 |
|-------------|-------------------|-----------------|-------------------|-----------------|------------------|-----------------|
|             | January 50% flows |                 | January 50% flows |                 | August Avg flows |                 |
|             | IMPACTS (%)       | IMPACTS (acres) | IMPACTS (%)       | IMPACTS (acres) | IMPACTS (%)      | IMPACTS (acres) |
| 44 ft depth | -5.0%             | -86             | -0.5%             | -20             | -3.2%            | -45             |
| 45 ft depth | -10.4%            | -179            | -0.5%             | -20             | -6.4%            | -89             |
| 46 ft depth | -15.9%            | -274            | -0.8%             | -32             | -9.5%            | -132            |
| 47 ft depth | -19.0%            | -328            | -0.8%             | -32             | -13.3%           | -185            |
| 48 ft depth | -21.6%            | -373            | -1.1%             | -44             | -15.8%           | -220            |

**Table 7.4.2.1-4: Fishery Impacts – Southern Flounder (Deepening Only)**

|             | August Avg flows |                 |
|-------------|------------------|-----------------|
|             | IMPACTS (%)      | IMPACTS (acres) |
| 44 ft depth | -0.3%            | -6              |
| 45 ft depth | -2.4%            | -45             |
| 46 ft depth | -2.4%            | -45             |
| 47 ft depth | -7.8%            | -146            |
| 48 ft depth | 0.0%             | 0               |

### 7.4.3 Water Quality & Dissolved Oxygen Modeling

To determine water quality impacts from SHEP, specifically changes in dissolved oxygen, both EFDC and WASP models were run; EFDC for hydrodynamic and salinity predictions and WASP for dissolved oxygen predictions. The Interagency Coordination Team specified run scenarios to evaluate water quality impacts. See **Table 7.4.3-1**.

**Table 7.4.3-1: Model Run Framework for Water Quality Impact Evaluation**

| Run Scenario            | Freshwater River Flow | Loading Conditions                        | Evaluation Period |
|-------------------------|-----------------------|-------------------------------------------|-------------------|
| Basic Evaluation        | Low Flow/Dry          | 2004 harbor point sources' BOD loads      | 1-May to 1-Nov    |
| Sensitivity Analysis #1 | Average/Typical       | 2004 harbor point sources' BOD loads      | 1-May to 1-Nov    |
| Sensitivity Analysis #2 | Low Flow/Dry          | 1999 harbor point sources' BOD loads      | 1-May to 1-Nov    |
| Sensitivity Analysis #3 | Low Flow/Dry          | Permitted Harbor Point sources' BOD loads | 1-May to 1-Nov    |

See **Table 7.4.3-2** for the point source loads referenced in the previous table.

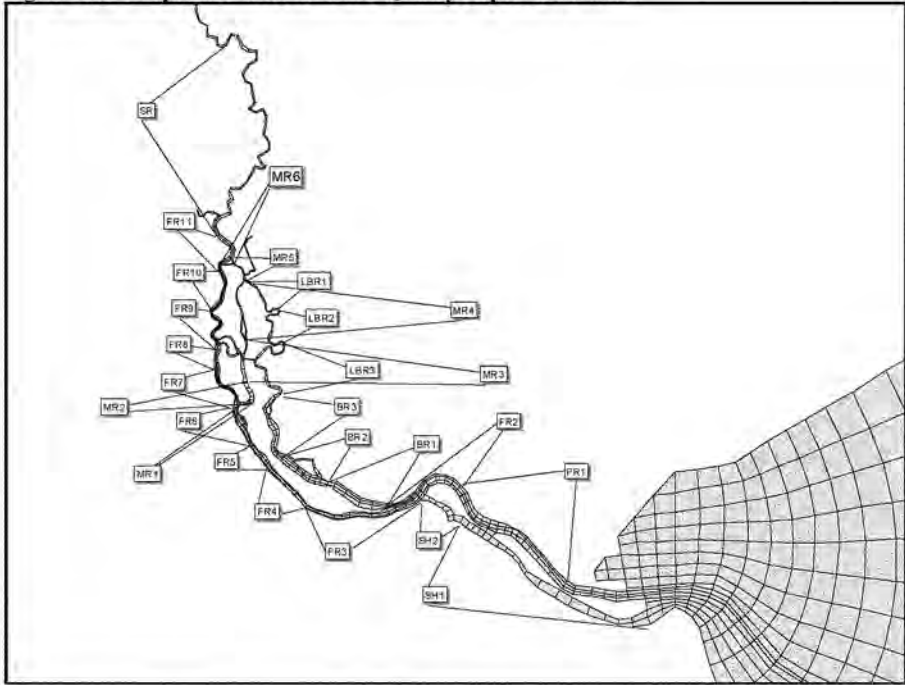
**Table 7.4.3-2: CBODu Point Sources Loads in Savannah Harbor**

| Facility name    | Location Cell (I_J) | Loads (lbs/day) |           |           |
|------------------|---------------------|-----------------|-----------|-----------|
|                  |                     | 2004            | 1999      | Permitted |
| Hardeeville      | 14_148              | 13.0            | 25        | 505.55    |
| Fort James       | 14_171              | 5,873.0         | 3,810.46  | 54,249.46 |
| Weyerhaeuser     | 13_95               | 6,797.0         | 809.86    | 30,150    |
| Garden City      | 13_77               | 32.0            | 122       | 2,700.7   |
| Wilshire         | 13_74               | 0.0             | 737.31    | 2,814.79  |
| Travis Field     | 13_74               | 27.0            | 129       | 576.35    |
| President Street | 13_54               | 1,489.0         | 4,398.99  | 16,246.15 |
| IP               | 15_70               | 143,448.0       | 86,669.75 | 269,328   |
| Engelhard        | 13_52               | 0               | 0.38      | 0         |

The Post Processor was also used to evaluate the WASP model output for ease in determining dissolved oxygen impacts by determining the following spatial objects:

- Critical Cell – the cell with lowest D.O. concentrations during specified simulation period
- Critical Segment – an assemblage of cross section cells located at the critical cell's j-coordinate
- Zone – an assemblage of cells that is limited by specified horizontal and vertical boundaries

Twenty-six spatial zones were delineated that cover the full estuary. See **Figure 7.4.3-1**.

**Figure 7.4.3-1: Spatial Zones for Water Quality Impact Evaluation**

Once the critical cells and segments were determined for each zone they were compared in the following ways:

- Comparing critical cells' D.O. concentrations for project scenarios and existing conditions with Georgia and South Carolina existing and proposed standards for D.O.
- Comparing zones' volume-weighted D.O. concentrations for existing and project scenarios, and D.O. standards.
- Comparing the percentage of water volume with D.O. concentrations that violate the D.O. standards for each zone during the selected simulation periods.
- Comparing the percentage of water volumes with specified salinity and D.O. percentiles for major parts and stations of the estuary.
- Comparing the percentage of water volumes in Upper Harbor in increments of 1°C of water temperature and 0.1 mg D.O.

- Analyzing values and their changes in longitudinal profiles of D.O. distributions along critical cells of Front, Back, Little Back, and Middle Rivers.
- Analyzing values and their changes in minimum, 5<sup>th</sup>, 50<sup>th</sup>, and 95<sup>th</sup> percentiles D.O. and salinity distributions in bottom and surface areas of the estuary
- Analyzing dynamics of 1-, 7-, and 30-day averaged D.O. and salinity and their changes in longitudinal - vertical plane of Front River.

#### 7.4.3.1 Findings

For greater detail on the water quality analysis and results for dissolved oxygen, see the report titled *Water Quality Impacts of the Savannah Harbor Expansion Project* included in the Engineering Investigations Supplemental Materials. Some short conclusions from the analysis of the report's results are listed below. A detailed analysis of the results can be found in the EIS.

##### Effect of the Harbor's Point Sources Loads

2004 and 1999 loads scenarios comparisons:

- The zones most affected by the harbor's point sources' impact are FR2-FR9, and BR1-BR3. The scenario of 2004 point sources loads serves as a benchmark for comparisons with other loads scenarios.
- The 1999 loads provide 6-8% (0.16 – 0.2 mg/l) improvement for the 1<sup>st</sup> percentile of D.O.; 2-5% (0.1-0.2 mg/l) improvement for the 50<sup>th</sup> percentile of D.O.; and 1-3% (0.02-0.15 mg/l) improvement for the 95<sup>th</sup> percentile of D.O. for critical cells of zones FR2-FR9. The D.O. deterioration is observed only for zone FR8 50 – 99 percentiles. The 1999 loads provide 8-11% (0.14 – 0.16 mg/l) improvement for the 1<sup>st</sup> percentile of D.O.; 4-12% (0.14-0.32 mg/l) improvement for the 50<sup>th</sup> percentile of D.O.; and 2-9% (0.11-0.35 mg/l) improvement for the 95<sup>th</sup> percentile of D.O. for critical cells of zones BR1-BR3.
- These tendencies persist for D.O. values averaged over the volumes of zones also. But deterioration of the D.O. regime for zone FR8 is not observed. Results indicate an increase in percentage of volumes with violations of existing and proposed D.O. standards for the 2004 loads scenario.
- Results show insignificant differences in D.O. distributions along the vertical-longitudinal plane of Upper Harbor for scenarios A and C.

2004 and permitted loads scenarios comparisons:

- Results show that 2004 loads provide 12-25 % (0.4 – 0.8 mg/l) improvement for the 1<sup>st</sup> percentile of D.O.; 6-14% (0.2-0.6 mg/l) improvement for the 50<sup>th</sup> percentile of D.O.; and 2-9% (0.1-0.6 mg/l) improvement for the 95<sup>th</sup> percentile of D.O. for critical cells of zones FR2-FR9. They also show that 2004 loads provide 21-32% (0.41 – 0.43 mg/l) improvement for the 1<sup>st</sup> percentile of D.O.; 12-14% (0.37-0.38 mg/l) improvement for the 50<sup>th</sup> percentile of D.O.; and 5-6% (0.24-0.25 mg/l) improvement for the 95<sup>th</sup> percentile of D.O. for critical cells of zones BR1-BR3.

- These tendencies persist for D.O. values averaged over the zones' volumes also. Results indicate an increase in percentage of volume with violations of existing and proposed D.O. standards for the permitted loads scenario.
- Results show significant differences in D.O. distributions along vertical plane of Upper Harbor for scenarios A and D.

#### Effect of 1999 (Drought) and 1997 (Average) Years Hydrological and Meteorological Conditions

- Results show that the increasing of river flow strongly effects the D.O. concentrations in critical cells particularly in zones of Back, Little Back and Middle Rivers, as well as Savannah River. The 1997 flow provide 10-50% increasing of the 1<sup>st</sup> D.O. percentile, 4-14% increasing of the 50<sup>th</sup> D.O. percentile, and 10-26% increasing of the 95<sup>th</sup> percentile for zones of the estuary.
- Results indicate that increases in D.O. concentrations averaged over volume of zones are up to 29 % for the 1<sup>st</sup> percentile, up to 10% for the 50<sup>th</sup> percentile, and up to 27% for the 95<sup>th</sup> percentile.
- The D.O. and salinity distributions along vertical plane of Upper Harbor for scenarios of 1997 and 1999 flows differ significantly.

#### Effect of the Harbor Deepening

- Results indicate the D.O. regime deterioration under the impact of the ship channel deepening mostly for critical cells of Front River zones F7, F8, and F9. For the drought year 1999 the D.O. decreases are up to 16.3% (1<sup>st</sup> and 50<sup>th</sup> percentiles, zone FR7) and 18.2% (99<sup>th</sup> percentile, zone FR7) for 6 ft deepening; and between 5.1% (1<sup>st</sup> percentile, zone FR7) and 1% (99<sup>th</sup> percentile, zone FR7) for 2 ft deepening. For the average year 1997 the D.O. decrease are 22.8% (1<sup>st</sup> percentile, zone FR9), 11.5% (50<sup>th</sup> percentile, zone FR9), and 5% (99<sup>th</sup> percentile, zone FR4) for 6 ft deepening, and between 8.3% (1<sup>st</sup> percentile, FR9), 6.6% (50<sup>th</sup> percentile, BR2), and 9.0% (99<sup>th</sup> percentile, BR2) for 2 ft deepening.
- Results indicate the D.O. regime deterioration under the impact of the ship channel deepening for D.O. values averaged over volume of zones. For the drought year 1999 the D.O. decrease are up to 11.1% (1<sup>st</sup> percentile, FR9), 8.2% (50<sup>th</sup> percentile, zone FR8), and 4.9% (99<sup>th</sup> percentile, zone FR7) for 6 ft deepening; and between 4.7% (1<sup>st</sup> percentile, zone FR7) and 1.7% (99<sup>th</sup> percentile, zone FR6) for 2 ft deepening. For the average year 1997 the D.O. decrease are 9.5% (1<sup>st</sup> percentile, zone FR9), 9.3% (50<sup>th</sup> percentile, zone FR7), and 10.5% (99<sup>th</sup> percentile, zone FR4) for 6 ft deepening; and 4.0% (1<sup>st</sup> percentile, FR9), 3.2% (50<sup>th</sup> percentile, FR7), and 4.2% (99<sup>th</sup> percentile, FR3) for 2 ft deepening.
- Results show that the deepening insignificantly (1-2%) increases the percentage of volume of the harbor's waters with violations of the existing D.O. standards.
- Results show the deteriorations of lowest D.O. values along critical cells of major parts of the estuary increase proportionally to projected deepening of the ship channel.

- Resulting figures visualize upstream shifts of lower D.O. zones in bottom and surface layers of the estuary with increasing of the harbor deepening.
- Resulting figures visualize an increase in salinity intrusions in bottom and surface layers of the estuary with increasing of the harbor deepening.
- Snapshots of animations of 1-, 7-, and 30-day averaged D.O. and salinity dynamics in vertical-longitudinal plane are presented in the results along the ship channel. The snapshots conclude higher channel deepening provides increasing of salinity and D.O. stratifications particularly for zones FR7, FR8, and FR9

#### 7.4.4 Wetland Modeling

The Interagency Coordination Team developed model run scenarios and outlined parameters to use in determining impacts to marshes and wetlands due to SHEP. Of particular interest are impacts to the freshwater tidal marshes adjacent to the estuary. The model scenarios outlined for the analysis vary by freshwater flow conditions at the upstream boundary and by sea level conditions at the ocean boundary. See **Table 7.4.4-1** for details on the model input parameters.

**Table 7.4.4-1: Wetland Evaluation Model Input Conditions**

| Run Scenario             | Freshwater River Flow | Sea Level Rise       | Evaluation Period    |
|--------------------------|-----------------------|----------------------|----------------------|
| Basic Evaluation         | Average/Typical       | Existing Sea Level   | 1-Mar to 1-Nov, 1997 |
| Sensitivity Analysis #1  | Low Flow/Dry          | Existing Sea level   | 1-Mar to 1-Nov, 2001 |
| Sensitivity Analysis #2A | Average/Typical       | 25 cm Sea Level Rise | 1-Mar to 1-Nov, 1997 |
| Sensitivity Analysis #2B | Average/Typical       | 50 cm Sea Level Rise | 1-Mar to 1-Nov, 1997 |

Standard practice for lake and reservoir models would be to calculate actual volume of storage using a high resolution digital elevation model. We do not think that approach is appropriate for estuaries. A significant amount of the volume in an estuary is due to tidal prism which is dependent upon tide range, depths in the estuary, and areas of inundation. Our measure of success was based on propagating the tides (water surface elevation comparisons) and volume of the water over a tidal period. We use measured flow data to calibrate volume. Since we could not account for all of the intricacies of the marsh areas in Savannah Harbor, we developed marsh grids to “size” the volumes needed to meet the tides. So when the chloride model was extended to account for the areas in and near Abercorn Creek, it was important to check the tidal flows and volumes. Modeled flow rates at Abercorn Creek were compared against measured flow rates for the same period, and their consistency demonstrated the ability of the modeled wetland storage areas to simulate the actual areas.

Freshwater river flows specified for the evaluations were determined using USGS gage data for Savannah River near Clio, Georgia. The EFDC model has continuous input boundary conditions for a 7 year period (1997-2003) available for simulation. Flow conditions during 1997 were found to be representative of the long term average and flow conditions during 2001 were considered to be a low flow (dry) period.

Sea Level Rise estimates were derived from the EPA published report titled *The Probability of Sea Level Rise* authored by J. G. Titus and V. K. Narayanan published October 1995 and specified for use



in wetland impact evaluation by the Interagency Coordination Team. Impacts to wetlands regarding sea level change over the 50-year project life are discussed further in Section 7.5.2.2 of this report.

#### 7.4.4.1 Findings

Impacts to marshes and wetlands during each run scenario were determined using riverine salinities predicted by the EFDC model. The EFDC model does not directly predict marsh salinity, despite the fact that the grid does include 17 marsh cells. These cells act primarily as storage areas and were found to be a critical model component for capturing the salinity trends in the upper part of the estuary, specifically, in Middle and Back River. Initially, these cells were equated with marsh acreages and used to predict marsh salinity and determine impacts. However, this proved to be an impractical way to determine changes in marsh salinities, especially changes in the freshwater/brackish marsh boundary line, and the idea was abandoned. The EFDC model grid was developed to predict changes in riverine salinity. The marsh cells were added to the model grid to enhance the riverine salinity calibration. The intended purpose of these 17 cells was not to predict and categorize the salinity changes within the marshes. Prior to abandonment, the results were documented in the report titled *Wetland/Marsh Impact Evaluation* which is included in the Engineering Investigations Supplemental Materials. See **Figure 7.4.4.1-1** for an example plot.

As an alternative, the wetland impacts were evaluated using a method where marsh salinity contour lines were extrapolated from the river into the marsh areas. The riverine salinities were predicted using the EFDC model results. This method creates contours that divide the marsh into 5 salinity categories: 0 - 0.5 ppt, which is considered freshwater, 0.6 - 1.0 ppt, 1.1 - 2.0 ppt, 2.1 - 4.0 ppt, and > 4.0 ppt. Acreages are then calculated based on these contours and impacts are assessed with comparisons. See **Figure 7.4.4.1-2** for an example. See **Table 7.4.4.1-1** for tabular results.

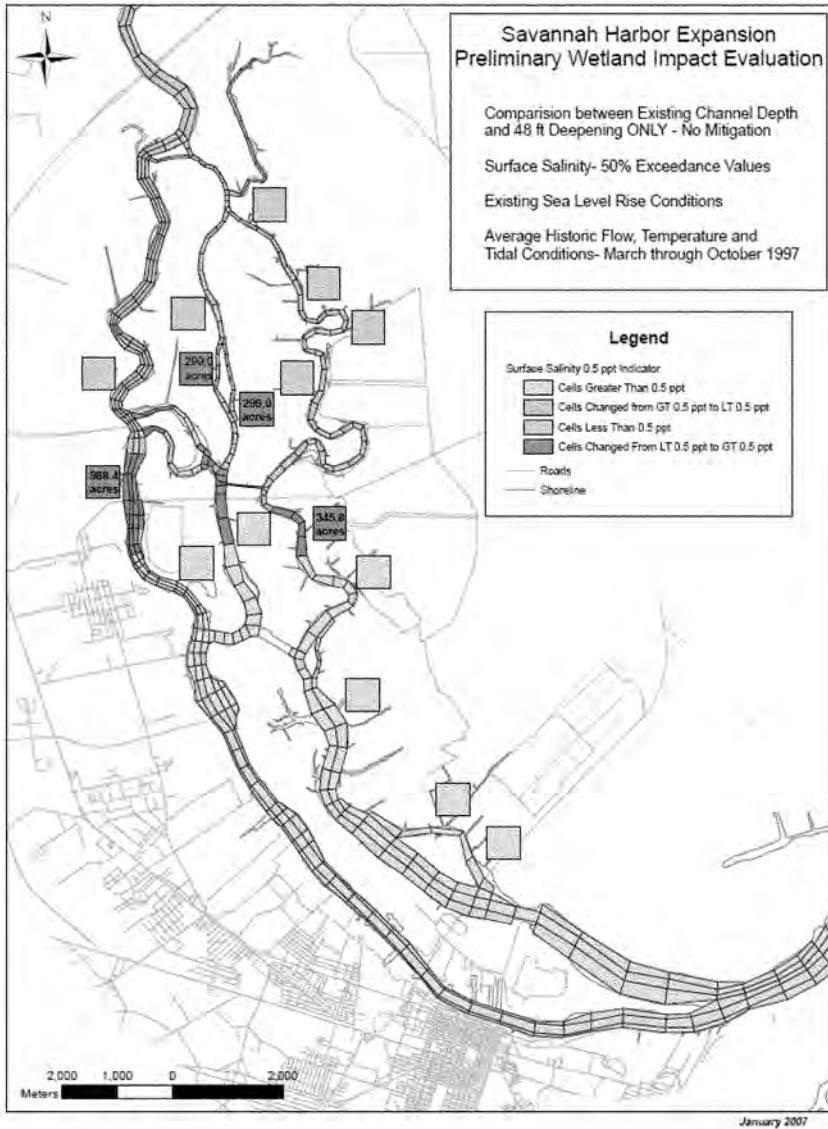
**Table 7.4.4.1-1: Estimated Marsh Salinity Acreages with the Basic Evaluation (Deepening Only)**

| Estimated Marsh Salinity (ppt) | Existing (acres) | 44 ft Depth (acres) | 45 ft Depth (acres) | 46 ft Depth (acres) | 47 ft Depth (acres) | 48 ft Depth (acres) |
|--------------------------------|------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| 0.0 - 0.5                      | 4072             | 3521                | 3105                | 3015                | 2895                | 2860                |
| 0.6 - 1.0                      | 864              | 1186                | 1319                | 1050                | 1009                | 830                 |
| 1.1 - 2.0                      | 555              | 397                 | 630                 | 921                 | 1355                | 1215                |
| 2.1 - 4.0                      | 834              | 863                 | 906                 | 789                 | 1365                | 739                 |
| > 4.0                          | 2506             | 2865                | 2873                | 3057                | 2208                | 3188                |

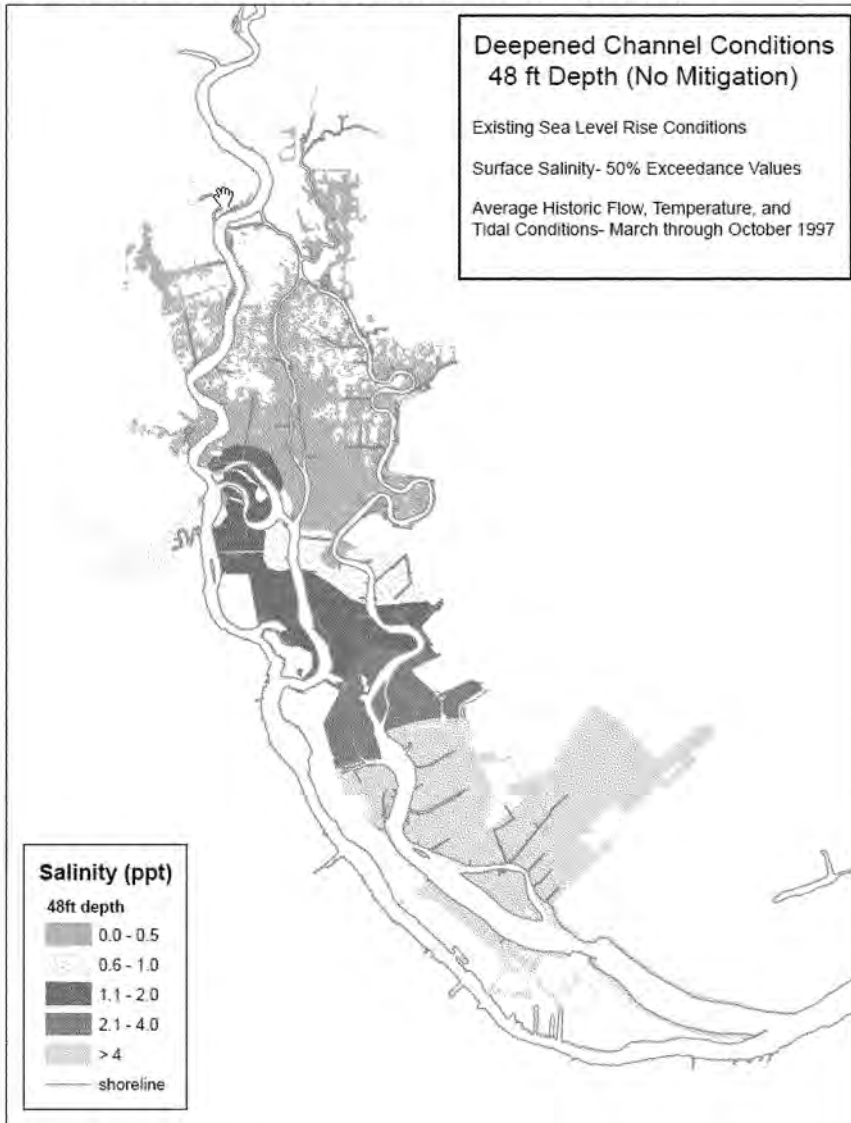
The development of the marsh salinity contour lines is highly subjective because they are extrapolated from the riverine salinities by hand. To ensure the validity of the results, verification and repeatability tests were done and concluded that the results are valid within +/- 50 acres.

In addition to the marsh salinity predictions and extrapolations, many maps and figures were developed to show changes in riverine salinity throughout the estuary. Most of the mapping focuses on surface salinities because it is within this layer of the water column that would have the most interaction with the adjacent marsh systems. The analysis details can be found in the *Wetland/Marsh Impact Evaluation* included in the Engineering Investigations Supplemental Materials and in the EIS.

**Figure 7.4.4.1-1: Changes in Freshwater Threshold Wetland Impact Evaluation**



**Figure 7.4.4.1-2: Wetland Salinity Projections for Wetland Impact Analysis**



#### 7.4.4.2 M2M/MSM

To aid in determinations of marsh salinity impacts for the EIS, the USGS entered into a cooperative agreement with the GPA to develop empirical models to simulate the water level salinity of the small creeks and tidal marshes adjacent to the estuary. This model is called Model-to-Marsh (M2M), an artificial neural network model, which provides a link from the hydrodynamic (EFDC) model salinity predictions to the marsh-succession model (MSM). The MSM simulates changes in plant distribution in the tidal marshes in response to changes in the water-level and salinity conditions due to geometry changes in the navigation channel. Details of M2M can be found in the USGS Scientific Investigations Report 2006-5187 titled *Simulation of Water Levels and Salinity in the Rivers and Tidal Marshes in the Vicinity of the Savannah National Wildlife Refuge, Coastal South Carolina and Georgia* included in the Engineering Investigations Supplemental Materials. Details of the MSM modeling can be found in the report titled *Savannah Harbor Deepening Project ATM Marsh Succession Model Marsh Wetland Impact Evaluation* dated May 2007 and the report titled *Savannah Harbor Deepening Project USGS/USFWS Marsh Succession Model Marsh Wetland Impact Evaluation* dated June 2007. Both of these reports are included in the Engineering Investigations Supplemental Materials.

The EIS includes a comparison of wetland impacts predictions using the method described in the previous section and impacts predicted by the MSM.

#### 7.4.5 Hurricane Surge Analysis

The purpose of the hurricane surge modeling is to determine the effect deepening the inner harbor navigation channel will have on the propagation of a hurricane storm surge traveling upstream through the estuary and river system. Simulations were run for the time period of August 18 – 23, 1997 using the EFDC model grid developed by Tetra Tech for the hydrodynamic modeling. The tidal boundary was modified to incorporate a synthetic storm surge. The specified time period was chosen for the following reasons:

- 1997 closely represents historic average flow conditions at the upstream flow boundary (USGS gage near Clio, GA)
- August is close to peak hurricane season when the likelihood of a large storm making landfall near the Savannah coastline would be more probable
- Spring tidal conditions occurred on August 19, 1997

The hurricane surge data set was developed by ATM and is based on measured water surface elevations collected at the USGS Customs House gage located in Charleston, SC during Hurricane Hugo, which made landfall on September 21, 1989. The hurricane storm surge component was separated from the harmonic tidal component for adaptation to the SHEP model. The maximum increase in water surface elevation for the hurricane storm surge component collected at the USGS Customs House gage was 7.69 ft. However, the storm surge as Hurricane Hugo made landfall varied with some places receiving a near 20-foot storm surge. Due to the difficulty in directly applying the storm surge gage data from Charleston to Savannah, the data set was ratioed to create three synthetic storm surges with peaks of 5, 10 and 15 ft. These storm surge data sets were then added to the harmonic tide in Savannah to create a synthetic storm surge scenario. Six storm event scenarios were developed from the data set. Three had the 5-, 10- and 15-foot peak surges occurring on top of the peak spring tidal condition. The fluctuation in water surface elevation in Savannah is so large that this peak-on-peak condition allowed evaluation of a worst case scenario. Three additional scenarios were

also evaluated that had the 5-, 10- and 15-foot peak storm surges occurring on the falling limb of the spring peak tide. The off-peak scenario would create a tidal surge that had a lower peak than the surge during the peak-on-peak scenario but would have a longer duration. There are likely some areas where a longer duration storm would be a worst case scenario rather than a shorter peak surge.

7.4.5.1 Model Limitations

The EFDC grid was not created with emphasis on hurricane surge modeling. The shipping channel and smaller side channels including marsh areas are described in the grid. However, the higher river banks and adjacent beaches are not accounted for in the model. These areas would likely be impacted during a hurricane and would have a direct effect on the propagation of a storm surge through the river system and navigation channel. The model is useful as a comparison tool to evaluate different deepening scenarios; however, it should only be used for relative comparative purposes and not to describe flooding depths and inundation limits during a hurricane event.

7.4.5.2 Findings

The results from the hurricane surge modeling show that the change in water surface elevation due to the deepening the inner harbor is not significant. **Table 7.4.5.2-1** shows the difference in the water surface elevation between the existing project depth and the maximum 48-foot deepening for three storm events simulated at two different times in the tide cycle. The maximum difference in the water surface elevations is 0.9 ft which occurs at the I-95 Bridge during the 15-foot surge at the peak of high tide.

**Table 7.4.5.2-1: Increase in Water Surface Elevation for 48-Ft Project Depth**

| Storm Surge Height | Increase in Water Surface Elevations |             |
|--------------------|--------------------------------------|-------------|
|                    | Ft. Jackson                          | I-95 Bridge |
| 5 Ft               |                                      |             |
| Peak on peak       | 0.3 ft                               | 0.7 ft      |
| Offset peaks       | 0.3 ft                               | 0.7 ft      |
| 10 Ft              |                                      |             |
| Peak on peak       | 0.3 ft                               | 0.8 ft      |
| Offset peaks       | 0.3 ft                               | 0.8 ft      |
| 15 Ft              |                                      |             |
| Peak on peak       | 0.3 ft                               | 0.9 ft      |
| Offset peaks       | 0.3 ft                               | 0.8 ft      |
| Maximum Difference | 0.3 ft                               | 0.9 ft      |

In addition to modeling the existing project and the 48-foot deepening scenarios, deepening the navigation channel elevations 44, 45, 46, and 47 ft below MLLW were also modeled for the 15-foot

surge during a peak-on-peak condition. This surge event was chosen because it has the greatest difference in water surface elevation between the existing and maximum deepening scenario. **Table 7.4.5.2-2** shows the resultant differences in water surface elevations for each modeled scenario.

**Table 7.4.5.2-2: Increase in Water Surface Elevation for 15-Foot Surge (Peak on Peak Condition)**

| Project Depth Alternatives | Increases in Water Surface Elevation |             |
|----------------------------|--------------------------------------|-------------|
|                            | Ft. Jackson                          | I-95 Bridge |
| 44 ft MLLW                 | 0.1 ft                               | 0.3 ft      |
| 45 ft MLLW                 | 0.2 ft                               | 0.5 ft      |
| 46 ft MLLW                 | 0.2 ft                               | 0.6 ft      |
| 47 ft MLLW                 | 0.3 ft                               | 0.8 ft      |
| 48 ft MLLW                 | 0.3 ft                               | 0.9 ft      |

While there are increases in the water surface elevations, the difference is not significant and is due to a larger volume of water being transported through the system during the tidal cycle and storm surge. This larger volume causes a slight increase in peaks on the flood tide and surge and a slight decrease in elevations on the ebb tide. In conclusion, the hurricane surge modeling shows that deepening the inner harbor has no significant adverse impact to a propagated storm surge as it travels upstream through the river system and navigation channel. Details of the hurricane surge analysis can be found in the report titled *Hurricane Surge Modeling* included in the Engineering Investigations Supplemental Materials.

## 7.5 MITIGATION FEATURE MODELING AND PLAN DEVELOPMENT

All mitigation feature modeling was evaluated using the same EFDC and WASP models discussed previously. Details on analysis of specific mitigation features and mitigation plan development can be found in the following sections and in the EIS.

### 7.5.1 Feature/Plan Development

The mitigation feature and plan development focuses on reducing adverse impacts associated with SHEP. Many ideas of how to accomplish this goal were already under discussion before modeling of the impacts was completed. Most of the ideas that required modeling focus on isolating portions of the estuary, specifically Middle and Back River to reduce impacts of deepening on Front River or rerouting flow paths by closing and opening various cuts. A conceptual list had been developed and portions pertaining to hydrodynamic and water quality modeling are shown in **Table 7.5.1-1**. A full list of conceptual mitigation ideas can be found in the EIS.

**Table 7.5.1-1: Conceptual Mitigation Actions**

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Wetlands</b><br><br>Restore sites where tidal freshwater wetlands previously existed.<br>Isolate Front River from Middle and Back Rivers to reduce salinity levels in MR and BR.<br>Close lower entrance of Middle River.<br>Install a flexible curtain as a barrier to block tidal flood flows up Middle River.<br>Construct berms along Front River to restrict high water flows across the marsh.<br>Block Rifle Cut to eliminate higher salinity water from MR entering Back River.<br>Block Drakies Cut and restore flows through Steamboat River to lengthen the passage of saline tidal waters up the Savannah River.<br>Cease operation of the Sediment Basin to reduce movement of salinity up Back River (fill in the Sediment Basin).<br>Begin operation of the tidegate with gates installed to only allow downstream flow, with no upriver movement of salt water.<br>Remove the tidegate. |
| <b>Fishery Resources</b><br><br>Increase dissolved oxygen levels in Front River.<br>Increase freshwater flows down Back River to improve striped bass habitat (velocities and salinity) during spawning.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Water Quality</b><br><br>Add air or oxygen to low Dissolved Oxygen waters.<br>Install air injection system on bottom of river.<br>Install floating aerators.<br>Install D.O. injection system on bottom of river.<br>Construct D.O. injection system on Hutchinson Island.<br>Mix low Dissolved Oxygen waters on the bottom with higher D.O. surface waters.<br>Inflatable weir.<br>Pumps.<br>Block Drakies Cut and restore flows through Steamboat River to lengthen the passage of saline tidal waters up Front River (decrease chloride levels at City of Savannah's I&D water intake).                                                                                                                                                                                                                                                                                                              |

### 7.5.2 Salinity & Freshwater Marsh Mitigation

Since tidal freshwater marshes were identified by the USFWS as the single most critical natural resource in the harbor, the Corps focused on reducing project impacts to that resource. Salinity is the primary determining factor in the conversion of tidal freshwater marshes, so that parameter was identified as the focus of the mitigation modeling efforts. The hydrodynamic model (EFDC) salinity concentration predictions were used to evaluate the mitigation features. A summary of how each

mitigation plan was finalized and selected is outlined below. Details of this process can be found in the EIS. Results for all plans evaluated can be found in the report titled *Mitigation Evaluation for Marsh/Wetland Impacts* included in the Engineering Investigations Supplemental Materials.

In the summer of 2006, several meetings were held to screen the mitigation options based on the EFDC model output. The first was held on July 12, 2006 and included the hydrodynamic modelers from the Corps and our consultants and scientists from various resources agencies. Model results were presented on maps showing salinity changes in the upper portion of the estuary adjacent to the freshwater tidal marshes. After lengthy discussion and review, features were either eliminated or put forward for further development. A summary of these model scenarios and notes on their viability as a mitigation feature are shown in **Tables 7.5.2-1** and **7.5.2-2**.

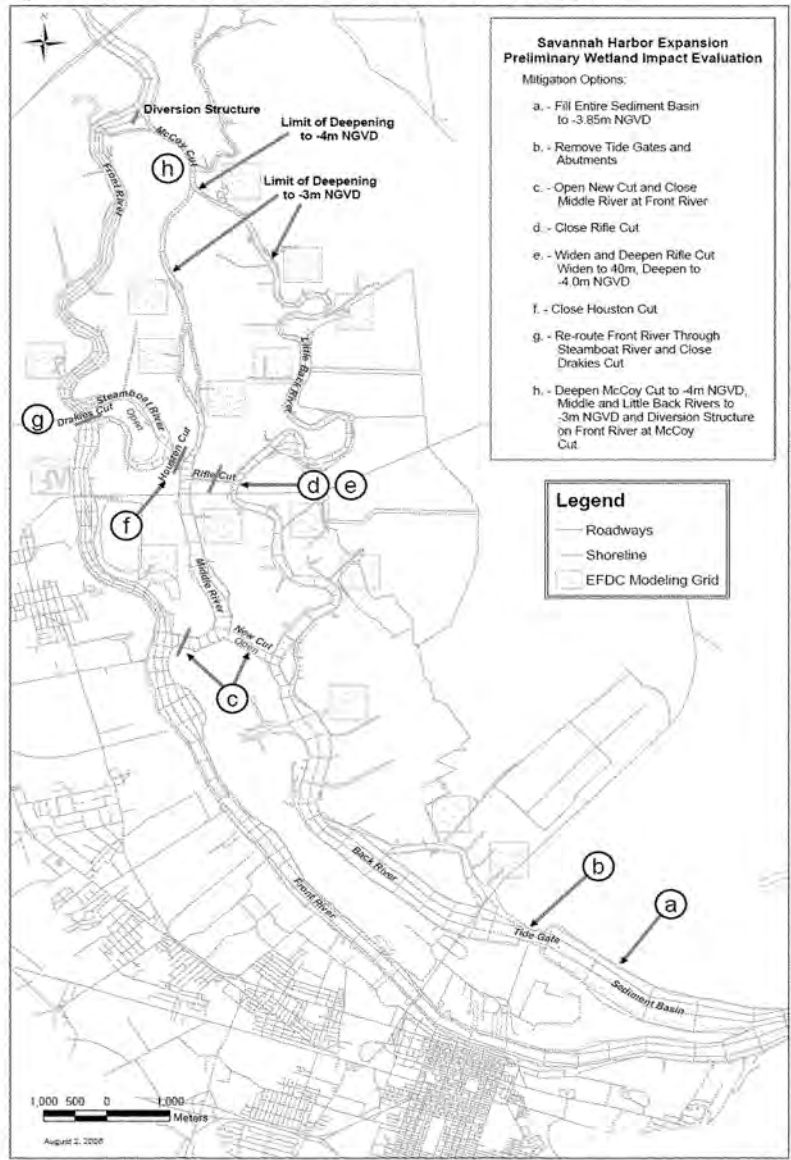
From this screening process, the mitigation features and the most effective design details of each feature (lengths, widths and depths) having the greatest potential to mitigate for SHEP impacts were identified. See **Figure 7.5.2-1** for a location map of these mitigation features. Details of these features, how they were modeled and how they mitigate for impacts follow the figure.







Figure 7.5.2-1: Potential Alterations to Water Flow for Mitigation



- a) Fill Entire Sediment Basin to -3.85m NGVD (-9.5 ft MLLW) The sediment basin is an O&M feature, located at the mouth of Back River that was constructed to allow for cost effective dredging maintenance of the channel. The sediment basin is approximately two miles long and 600 ft wide and has an authorized maintenance depth of -40 ft MLLW (-13.1m NGVD), near the bottom of the navigation channel. The sediment basin currently acts as a trap for sediments but also traps salinity which, due to the depths in the basin, can more readily move upstream through the tidegate into the Back River system. This is especially true during dry times when freshwater inflows coming downstream are low.

Upstream of the sediment basin, the elevation of Back River is controlled by the sill on the tidegate structure at -9.5 ft MLLW (-3.85 m NGVD). By discontinuing the use of the sediment basin as a maintenance feature and allowing it to fill naturally, the current upstream elevation on Back River could be extended through the sediment trap to the confluence with Front River. The modeling results show that filling the basin reduces salinity concentrations upstream in Back River by allowing more mixing and flushing of the area on each tidal cycle. Also, salinity concentrations are reduced by limiting the interaction between the Back River and the lowest portions of the water column on Front River that have the highest concentrations of salinity. Due to the fact that the sediment basin does provide a cost effective means of maintaining the channel, efforts were made to preserve some of its function. Several different filling scenarios were evaluated to determine if effectiveness of reducing salinity upstream on Back River could be achieved by limiting the function of the basin without eliminating it entirely. However, those scenarios were not as effective at reducing impacts from SHEP as letting the basin fill to the same elevation of the tidegate at -9.5 ft MLLW (-3.85 m NGVD).

- b) Remove Tidegates and Abutments Upstream of the sediment basin on Back River is another O&M feature of the channel known as the tidegates. The tidegates were constructed during the same time as the sediment basin, but have since been taken out of use. The structure still stands with a sill elevation at -9.5 ft MLLW (-3.85 m NGVD) but the gates themselves have been removed. The gates were taken out of operation and removed because of environmental impact concerns with trapping high concentrations of salinity in the Back River system. Though the gates themselves have been removed, the structure still restricts flow moving in and out of the Back River system. Eliminating this constriction requires removing the tidegate abutments that support the structure.

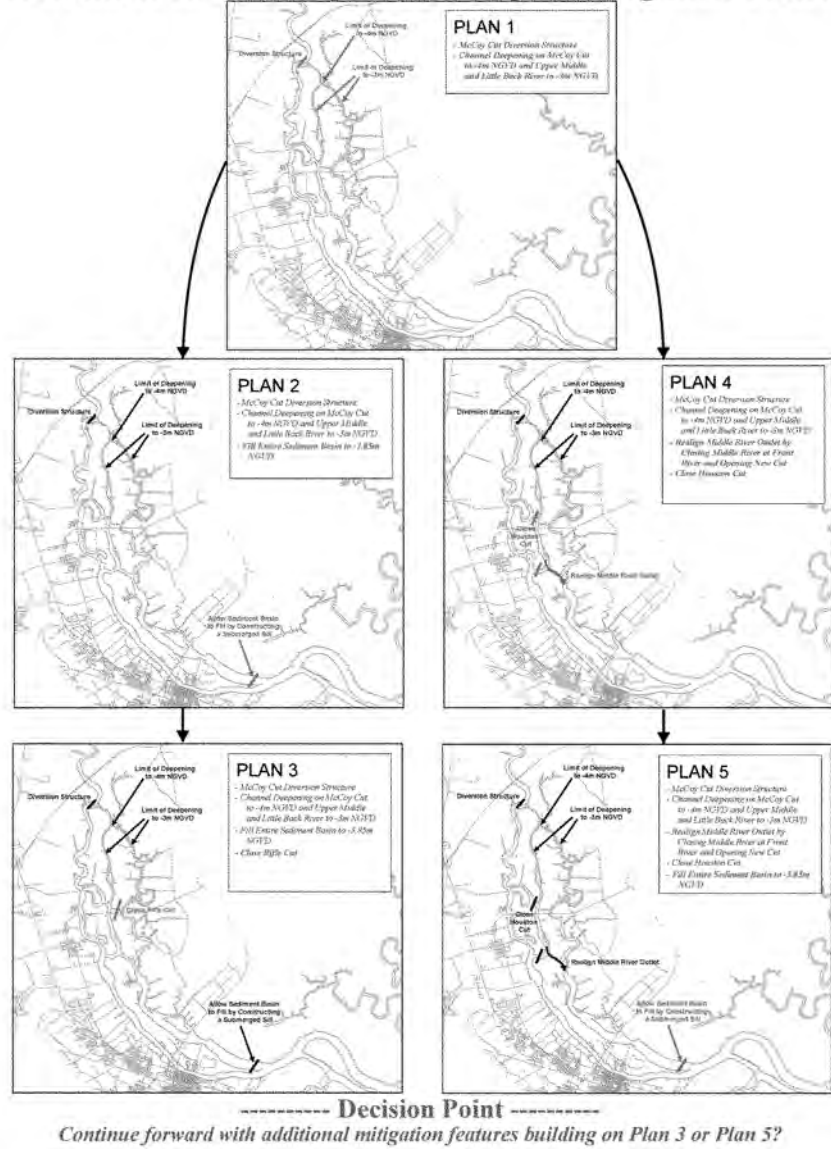
Due to the complexity of the river system, this constriction prevents water from flowing both upstream on the incoming tide and downstream on the outgoing tide. Removing the abutments allows more freshwater flow and mixing to occur while not allowing more salinity to intrude upstream on Back River.

- c) Open New Cut and Close Middle River at Front River New Cut was constructed the same time as the tidegate and sediment basin and was an integral part of the design plan to reduce O&M costs in the harbor. However, it was closed in 1992. New Cut once provided a link between Middle River and Back River; however, concerns about salinity intrusion from Front River through the cut to Middle and Back River was part of the reason it was closed. Re-opening New Cut requires that the Middle River/Front River connection be closed. This would essentially re-route Middle River through Back River and eliminate its connection with Front River. By eliminating the connection between Middle and Front River, the high saline concentrations moving up the deep navigation channel cannot enter into the Back River system.

- d) Close Rifle Cut Rifle Cut is a very small cut between Middle River and Little Back River. Despite its small size, it transports large volumes of water between the two rivers on each tidal cycle. Eliminating the cut has the same rational as mentioned above in feature c) Open New Cut and Close Middle River at Front River. The closure would allow isolation of Little Back River from the higher salinity water in Middle River.
- e) Widen and Deepen Rifle Cut- Widen to 40m and Deepen to -4.0 m NGVD Due to the high transport capacity through Rifle Cut, widening and deepening the cut was proposed in hopes of increasing the amount of fresh water exchange between Middle River and Little Back River. The flow regime through the cut is complex, and initially it was not understood if closing or enlarging would provide the greatest benefits. Also, due to the complexity of the system on a whole, closing or enlarging Rifle Cut may be more or less effective based on the other features that are coupled with this one.
- f) Close Houston Cut Closing Houston Cut has the potential to isolate Middle River from Front River and Steamboat River. Isolation would aid in eliminating the transmission of high salinity water from Front River through the cut.
- g) Re-route Front River Through Steamboat River and Close Drakies Cut Re-routing Front River through Steamboat River by closing Drakies Cut restores a historic bend in the river. The bend is just over 2 miles long. It is believed that re-routing tidal waters through this bend would increase travel times on Front River during each incoming tide that would reduce the distance that salinity could travel upstream on any given tide, thereby reducing salinity intrusion and impacts upstream of the cut. However, the proximity of Steamboat River to Houston Cut, almost requires that the two features be evaluated in combination. Re-routing Steamboat without closing Houston Cut, increases the transport potential between Middle River and the high salinity concentrations on Front River. While benefits may be gained on Front River upstream of Drakies Cut, greater impacts may be seen on Middle and Back River through the Houston Cut access.
- h) Deepen McCoy Cut to -4m NGVD, Middle and Little Back Rivers to -3m NGVD and Diversion Structure on Front River at McCoy Cut Deepening these areas and constructing a diversion structure would allow greater amounts of fresh water flowing downstream on the Savannah to enter into the Back River system via McCoy Cut. By providing larger volumes of fresh water, the Back River system has greater flushing capacity, especially on the outgoing tide, to wash more saline water downstream and out of the system. Also, this feature would provide a barrier to higher concentrations of saline water coming up through the system from the access points on Middle River and through the sediment basin.

Due to the complexity of the system, mitigation features were also evaluated in combination. An initial screening of the features to be evaluated in combination was completed by the Corps and the Interagency Coordination Team reviewed the results. A plan to evaluate these features in combination was established. See **Figures 7.5.2-2 and 7.5.2-3**.

**Figure 7.5.2-2: Mitigation Plans 1 – 5**  
***Savannah Harbor Expansion Project Mitigation Plans***



Once mitigation Plans 1 – 5 were evaluated a collaborative decision was made to continue with plan development following Plan 3 or Plan 5. Upon review of Plan 5, it was discovered that the flow-altering features required to re-route Middle River have two negative impacts:

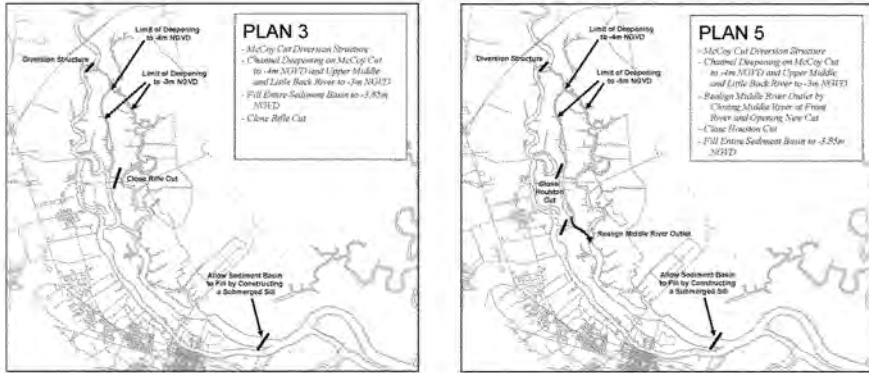
- The tidal range is decreased through Middle, Back and Little Back Rivers in a way that could negatively affect wetlands dependent on receiving freshwater tidal flows.
- Fish migrating through the estuary would no longer have the Middle River/Front River connection or pathway through Houston Cut to use for migration.

Based on these potential problems with mitigation Plan 5, it was eliminated as an alternative.

Mitigation Plan 3 was then further developed with inclusion of features outlined in **Figure 7.5.2-3**.

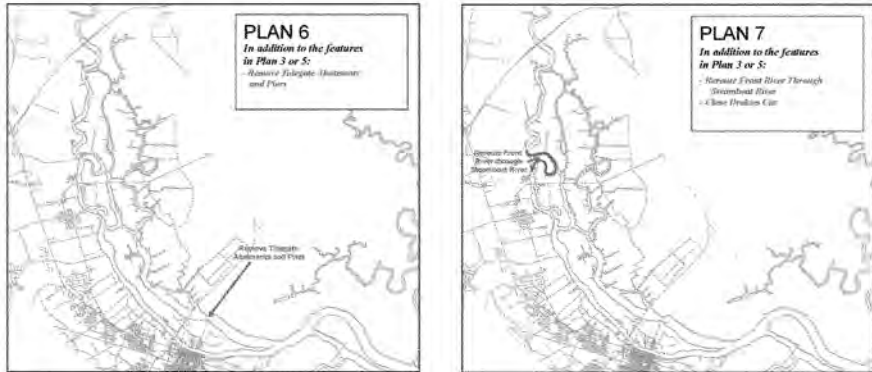
Figure 7.5.2-3: Mitigation Plans 6 &amp; 7

## Savannah Harbor Expansion Project Mitigation Plans



### ----- Decision Point -----

Continue forward with additional mitigation features building on Plan 3 or Plan 5?





At this point, Plan 6 and Plan 7 were compared and evaluated for effectiveness both from an impacts perspective and a cost perspective. Plan 7 is a mitigation concept that is particularly interesting involving re-routing Front River through Steamboat River. Steamboat River is historically the route of Front River prior to the construction of Drakes Cut. The adjustments made to the model to predict the results of plan 7 were complex and required close scrutiny to ensure the additional mitigation feature was modeled accurately. See **Figure 7.5.2-4** for an aerial view of Steamboat River.

The model predictions for Plan 7 show that the additional mitigation feature, routing Front River through Steamboat, does provide additional mitigation benefits. For the 48 ft deepening, the mapping shows that the freshwater zone ends just below Steamboat as compared to Plan 3 where the freshwater zone ends above Steamboat. It may be counterintuitive to think that the freshwater zone around Steamboat would remain fresh with the Front River routed through it. However, what the modeling shows is that when Steamboat is widened and deepened, the salinity becomes more stratified and the velocities increase. This change in geometry allows the less dense fresh water to stay on top of the water column and flush through the bend while providing fresh water to the marshes. In Plan 3 and under existing conditions, Steamboat is smaller and shallower. Velocities are low and the water column is less stratified. This allows more saline water to be available in the surface layer of the water column, for a longer period of time, to interact with the marsh; thus causing the freshwater zone to move above Steamboat. Despite the shallow depth of the sill at Houston Cut (-2.2 m NGVD), saline water moves from Steamboat through Houston Cut to Middle River and causes increases in surface salinity on Middle River. However, surface salinities on Front River above Steamboat are greatly reduced by lengthening the path that the saline water has to travel during each tidal cycle. The predominate path for surface salinity to move through the upper portion of the river system is Middle River. Near McCoy's Cut, the surface salinities on Middle River are much higher than that of Front River. The salinity movement on Middle River appears to supply salinity to the upper portion of Little Back River.

Plan 7 does appear to be more effective in mitigating the impacts due to deepening than Plan 3 when viewing the acreage impacts based on the 50th percentile salinity contours. For the 48 ft depth, there is approximately 180 more freshwater marsh/wetland acres available. However, at the 48 ft depth, Plan 7 does not fully mitigate the impacts to freshwater marsh/wetlands and additional mitigation measures would likely be required. Despite the benefits shown by computing the 50th percentile surface salinities and subsequent marsh/wetland acreages impacted, Plan 7 does appear to increase surface salinity on Middle River. As shown in **Table 7.5.2-3**, surface salinity on Middle River increases significantly for percentiles greater than 50. The increases on Middle River are more pronounced with drought flows. During those high tide periods, Plan 7 has the potential to provide more saline water to wetlands than that of Plan 3.

Figure 7.5.2-4: Steamboat River



Table 7.5.2-3: Surface Salinity Percentile Value Comparisons

| Percentile | Existing Conditions | Plan 3<br>48 ft Depth | Plan 7<br>48 ft Depth |
|------------|---------------------|-----------------------|-----------------------|
| 10         | 0.00                | 0.00                  | 0.00                  |
| 20         | 0.01                | 0.02                  | 0.01                  |
| 30         | 0.05                | 0.06                  | 0.04                  |
| 40         | 0.11                | 0.14                  | 0.11                  |
| 50         | 0.20                | 0.27                  | 0.24                  |
| 60         | 0.33                | 0.45                  | 0.48                  |
| 70         | 0.48                | 0.68                  | 0.82                  |
| 80         | 0.68                | 1.06                  | 1.42                  |
| 90         | 1.00                | 1.63                  | 2.54                  |

*\*All salinity values are from Middle River – Grid Cell 26\_102*

For these reasons, along with high construction costs, Plan 7 was eliminated from further review. Plan 6, however, did show value over Plan 3 and was further evaluated.

Through the mitigation development process, additional features had been identified as potentially effective at reducing salinity and were also evaluated. See **Table 7.5.2-4** for a matrix of these additional plans. Model results for these plans along with all other plans evaluated can be found in the report titled *Mitigation Evaluation for Marsh/Wetland Impacts* included in the Engineering Investigations Supplemental Materials.

**Table 7.5.2-4: Additional Mitigation Plan Alternatives**

|         | McCoy Cut<br>Diversion<br>Structure | Channel<br>Deepening on<br>McCoy, Upper<br>Middle and Little<br>Back River | Fill Entire<br>Sediment Basin | Close Rifle Cut | Close Lower<br>(western) Arm at<br>McCoy Cut | Remove Tidegate<br>Abutments and<br>Piers |
|---------|-------------------------------------|----------------------------------------------------------------------------|-------------------------------|-----------------|----------------------------------------------|-------------------------------------------|
| Plan 3  | x                                   | x                                                                          | x                             | x               |                                              |                                           |
| Plan 3a | x                                   | x                                                                          | x                             | x               | x                                            |                                           |
| Plan 3b | x                                   |                                                                            | x                             | x               |                                              |                                           |
| Plan 3c | x                                   |                                                                            | x                             | x               | x                                            |                                           |
| Plan 6  | x                                   | x                                                                          | x                             | x               |                                              | x                                         |
| Plan 6a | x                                   | x                                                                          | x                             | x               | x                                            | x                                         |
| Plan 6b | x                                   |                                                                            | x                             | x               | x                                            | x                                         |

The following table, **Table 7.5.2-5**, shows a summary of the estimated marsh salinity impacts for only the freshwater marsh zone (0.0 to 0.5 ppt) for each of the mitigation plans described above for the full 48 ft proposed channel depth (a greatest impact condition). These calculations, along with cost considerations were factors in selecting the final mitigation plan.

**Table 7.5.2-5: Estimated Marsh Acreages for Additional Mitigation Plans**

| Modeled Scenario    | Estimated Freshwater Marsh Acreages<br>(0.0 – 0.5 ppt) |
|---------------------|--------------------------------------------------------|
| Existing Conditions | 4072                                                   |
| 48 ft Depth ONLY    | 2860                                                   |
| Plan 3              | 3584                                                   |
| Plan 3a             | 3531                                                   |
| Plan 3b             | 3406                                                   |
| Plan 3c             | 3383                                                   |
| Plan 6              | 3715                                                   |
| Plan 6a             | 3735                                                   |
| Plan 6b             | 3610                                                   |

*All mitigation plans were evaluated with the 48 ft channel depth.*

The process of developing mitigation features and evaluating their effectiveness has been an ongoing, collaborative effort between the PDT and the Interagency Coordination Team. All of the mitigation scenarios were evaluated, alone and in combination, based on the effectiveness at reducing salinity impacts, observed in the initial modeling, and preliminary estimates of construction costs. Details of how each mitigation plan was finalized and selected can be found in the EIS. Model results for all plans evaluated can be found in the report titled *Mitigation Evaluation for Marsh/Wetland Impacts* included in the Engineering Investigations Supplemental Materials.

### 7.5.2.1 Proposed Mitigation Features

Based on analysis of the model output, the flow-altering mitigation plans that were found to be the most effective at reducing salinity impacts and protecting freshwater tidal marshes are Plan 6a for the 48 ft, 47 ft, 46 ft, and 45 ft channel depths and 6b for the 44 ft channel depth. Although the plans do not fully mitigate for all impacts to the estuary, they are expected to provide substantial benefits to the freshwater marsh ecosystems adjacent to the Back and Little Back Rivers. For details on the model output for these two selected flow-altering scenarios see the EIS and report titled *Evaluation of Marsh/Wetland Impacts with Proposed Mitigation Plan* dated November 2007 and the *Addendum* dated July 2011 which are both included in the Engineering Investigations Supplemental Materials.

Plan 6b is the proposed flow-altering mitigation plan for the 44 ft channel depth. The features of this plan include a diversion structure on Front River, closure of the lower (western) arm at McCoy Cut, closure of Rifle Cut, filling of the Sediment Basin and removal of the tidegate abutments and piers. This plan provides potential for additional freshwater flows to enter the Back River System at McCoy Cut, without exiting through the lower (western) arm, and flow downstream through Middle, Back and Little Back Rivers. It also has features that will limit salt water intrusion to the Back River area through the sediment basin and Rifle Cut. See **Figure 7.5.2.1-1**.

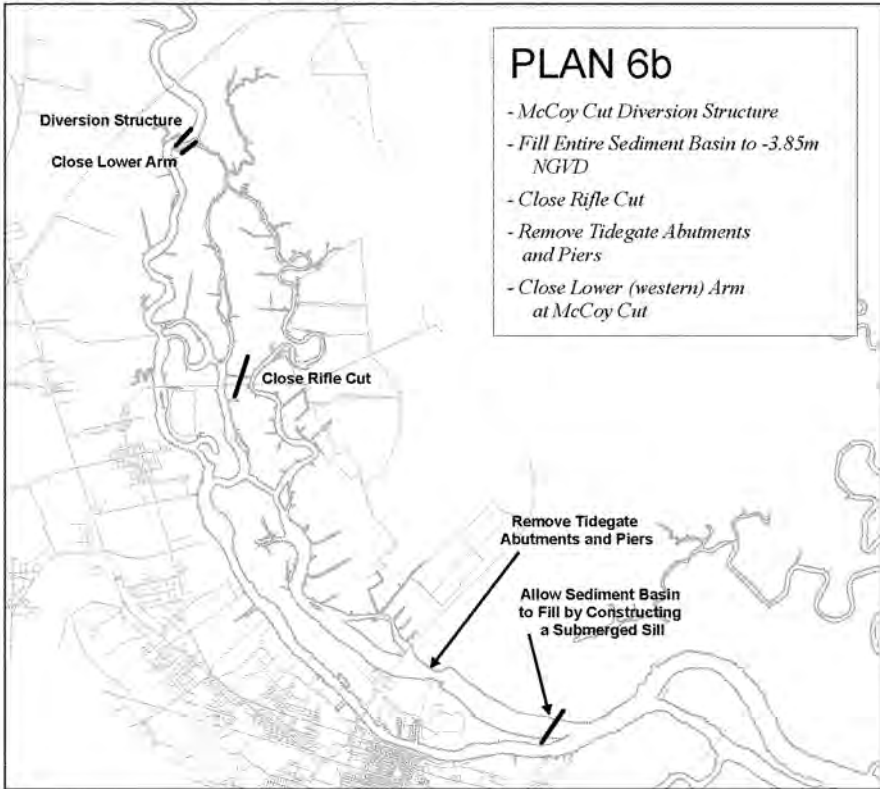
The modeling results, regarding wetland impacts, for implementing mitigation Plan 6b with the 44 ft depth are shown in **Table 7.5.2.1-1**. A plot of the estimated wetland impacts for the 44 ft depth with mitigation Plan 6b is shown in **Figure 7.5.2.1-2**. The estimated freshwater marsh salinity impacts (range 0.0 – 0.5) are fully mitigated with the 44 ft channel depth with mitigation Plan 6b, i.e. there is no net loss. The additional created freshwater wetlands are adjacent to Middle and Back River where the mitigation plan has the greatest effect.

Plan 6a is the proposed mitigation plan for the 45, 46, 47, and 48 ft channel depths. This plan includes all the features of Plan 6b and one additional feature, channel deepening on McCoy Cut, upper Middle and Little Back Rivers. This additional feature in combination with the features in Plan 6b maximizes the potential for additional freshwater flows to enter the Back River System at McCoy Cut and flow downstream through Middle, Back and Little Back Rivers. See **Figure 7.5.2.1-3**.

The modeling results, regarding wetland impacts, for implementing mitigation Plan 6a with the 45, 46, 47 and 48 ft depth are shown in **Table 7.5.2.1-2**. A plot of the estimated wetland impacts for the 48 ft depth with mitigation Plan 6a is shown in **Figure 7.5.2.1-4**. The estimated freshwater marsh salinity impacts (range 0.0 – 0.5) are not fully mitigated with the 48 ft channel depth with mitigation Plan 6a, there is a net loss under the average flow conditions. The losses are largely adjacent to Front River where the deepening is occurring, which makes mitigation in these areas very difficult. The marsh salinity estimates show that wetlands are protected and created adjacent to Middle and Back River

where the mitigation plan has the greatest effect. However, the created freshwater wetlands are not large enough to fully mitigate for the losses of freshwater wetlands on Front River.

**Figure 7.5.2.1-1: Flow-altering Mitigation Plan 6b**



**Table 7.5.2.1-1: Wetland Acreages with Mitigation Plan 6b for Basic Evaluation**

| <b>Salinity Range (ppt)</b> | <b>Existing No Deepening No Mitigation</b> | <b>44 ft Depth Deepening Only No Mitigation</b> | <b>44 ft Depth &amp; Mitigation Plan 6b</b> |
|-----------------------------|--------------------------------------------|-------------------------------------------------|---------------------------------------------|
| 0.0 – 0.5                   | 4072                                       | 3521                                            | 4394                                        |
| 0.6 – 1.0                   | 864                                        | 1186                                            | 1137                                        |
| 1.1 – 2.0                   | 555                                        | 397                                             | 749                                         |
| 2.1 – 4.0                   | 834                                        | 863                                             | 855                                         |
| > 4.0                       | 2506                                       | 2865                                            | 1698                                        |

Figure 7.5.2.1-2: Estimated Wetland Impacts with 44 ft Depth and Mitigation Plan 6b

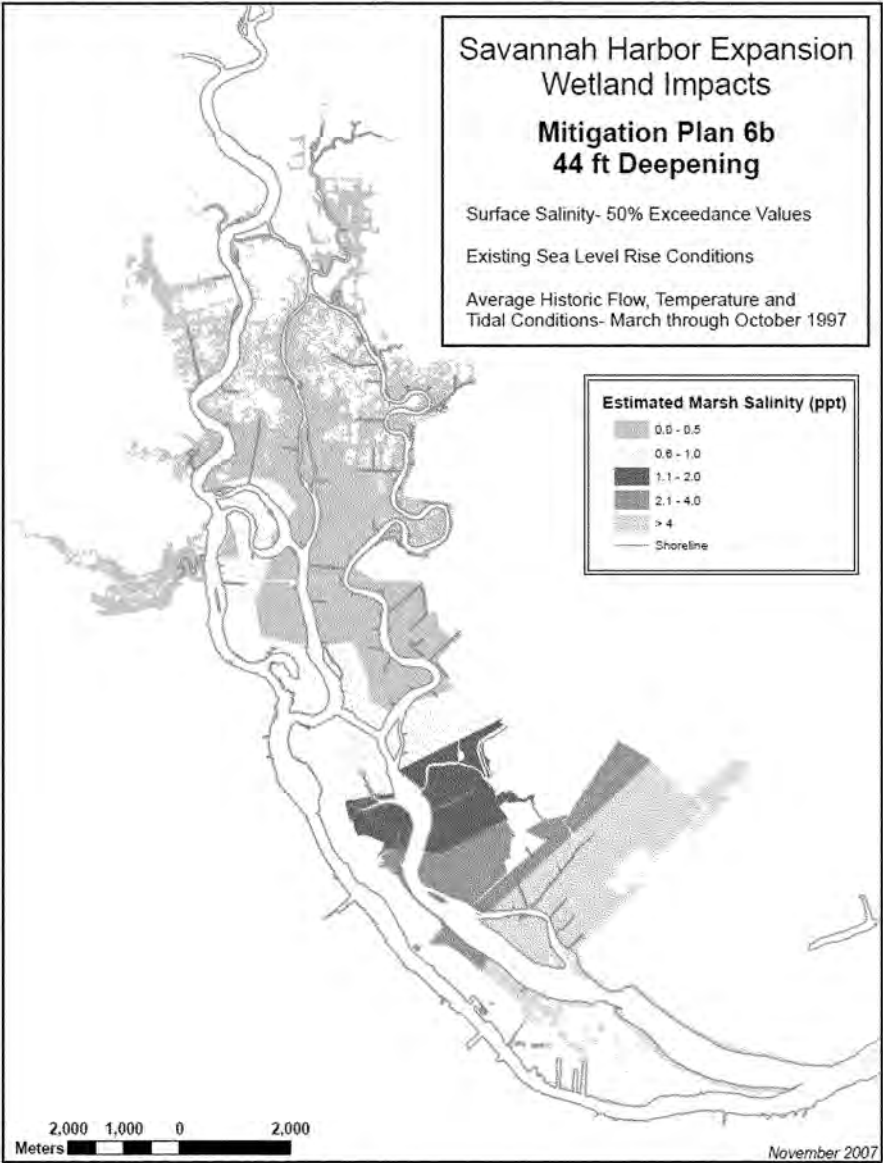
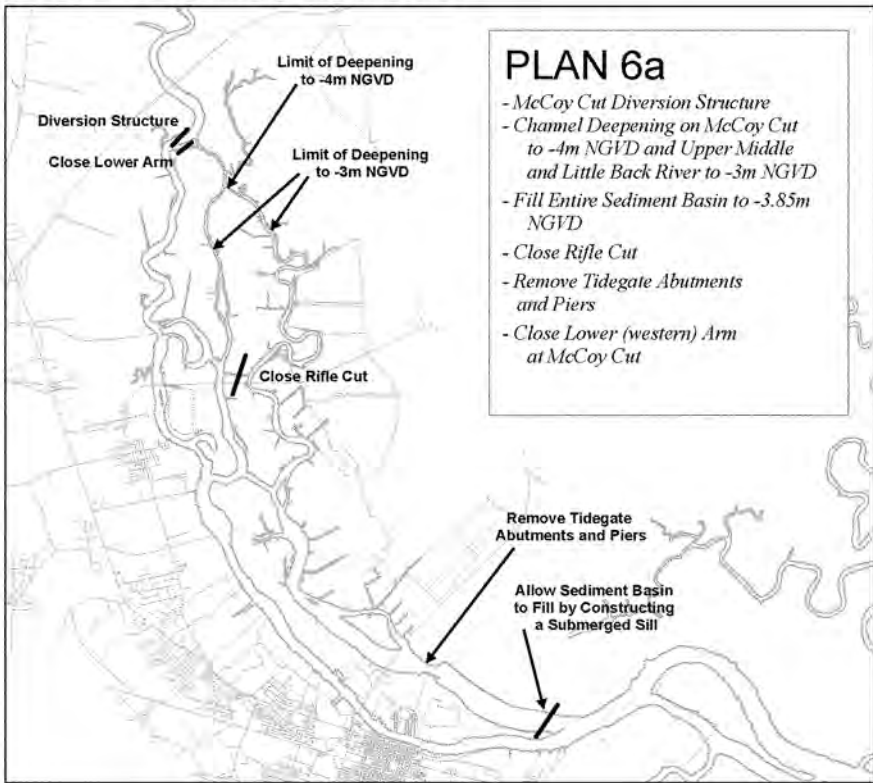


Figure 7.5.2.1-3: Flow-altering Mitigation Plan 6a

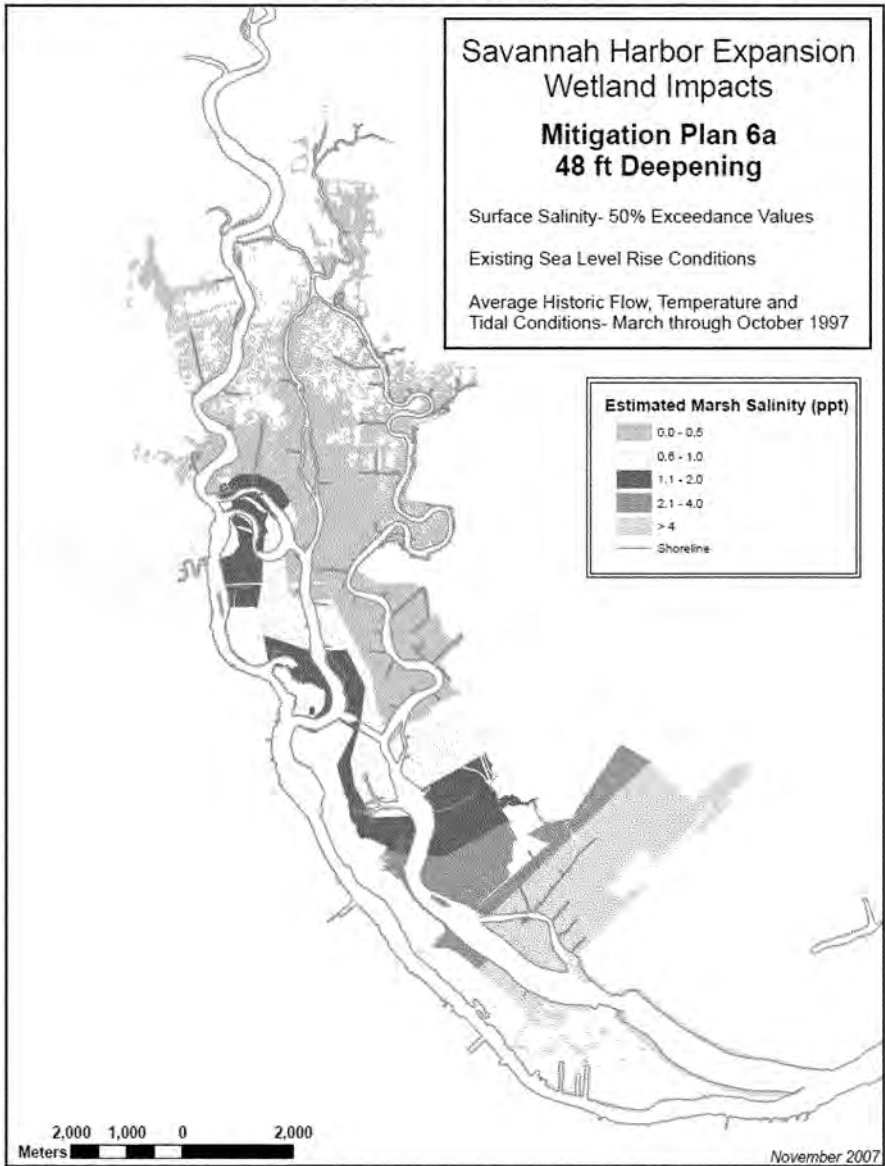




**Table 7.5.2.1-2: Wetland Acreages with Mitigation Plan 6a for Basic Evaluation**

| <b>Salinity Range (ppt)</b> | <b>Existing No Deepening No Mitigation</b> | <b>45 ft Depth Deepening Only No Mitigation</b> | <b>45 ft Depth &amp; Mitigation Plan 6a</b> |
|-----------------------------|--------------------------------------------|-------------------------------------------------|---------------------------------------------|
| 0.0 – 0.5                   | 4072                                       | 3105                                            | 4040                                        |
| 0.6 – 1.0                   | 864                                        | 1319                                            | 1781                                        |
| 1.1 – 2.0                   | 555                                        | 630                                             | 588                                         |
| 2.1 – 4.0                   | 834                                        | 906                                             | 745                                         |
| > 4.0                       | 2506                                       | 2873                                            | 1678                                        |
| <b>Salinity Range (ppt)</b> | <b>Existing No Deepening No Mitigation</b> | <b>46 ft Depth Deepening Only No Mitigation</b> | <b>46 ft Depth &amp; Mitigation Plan 6a</b> |
| 0.0 – 0.5                   | 4072                                       | 3015                                            | 3871                                        |
| 0.6 – 1.0                   | 864                                        | 1050                                            | 1650                                        |
| 1.1 – 2.0                   | 555                                        | 921                                             | 862                                         |
| 2.1 – 4.0                   | 834                                        | 789                                             | 700                                         |
| > 4.0                       | 2506                                       | 3057                                            | 1749                                        |
| <b>Salinity Range (ppt)</b> | <b>Existing No Deepening No Mitigation</b> | <b>47 ft Depth Deepening Only No Mitigation</b> | <b>47 ft Depth &amp; Mitigation Plan 6a</b> |
| 0.0 – 0.5                   | 4072                                       | 2895                                            | 3849                                        |
| 0.6 – 1.0                   | 864                                        | 1009                                            | 1641                                        |
| 1.1 – 2.0                   | 555                                        | 1355                                            | 889                                         |
| 2.1 – 4.0                   | 834                                        | 1365                                            | 687                                         |
| > 4.0                       | 2506                                       | 2208                                            | 1766                                        |
| <b>Salinity Range (ppt)</b> | <b>Existing No Deepening No Mitigation</b> | <b>48 ft Depth Deepening Only No Mitigation</b> | <b>48 ft Depth &amp; Mitigation Plan 6a</b> |
| 0.0 – 0.5                   | 4072                                       | 2860                                            | 3735                                        |
| 0.6 – 1.0                   | 864                                        | 830                                             | 1340                                        |
| 1.1 – 2.0                   | 555                                        | 1215                                            | 1191                                        |
| 2.1 – 4.0                   | 834                                        | 739                                             | 790                                         |
| > 4.0                       | 2506                                       | 3188                                            | 1776                                        |

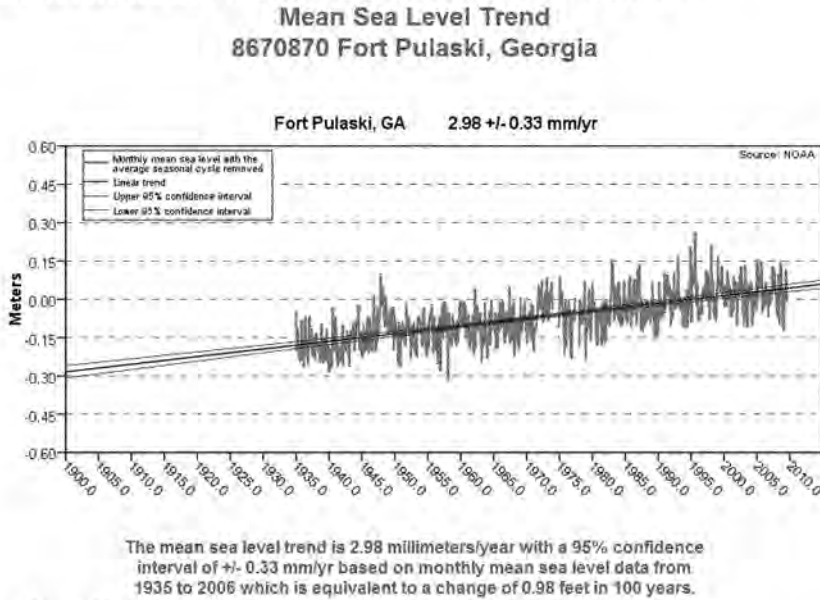
**Figure 7.5.2.1-4: Estimated Wetland Impacts with 48 ft Depth and Mitigation Plan 6a**



### 7.5.2.2 Relative Sea Level Change

According to NOAA, the historic sea level change trend at the Fort Pulaski gage based on 70 plus years of data collection is a rise of 2.98 mm/year (see **Figure 7.5.2.2-1**), which is a combination of the global sea-level rise and local vertical land movement. Scientific opinions vary on how this trend will continue in the coming years with the effect of greenhouse gases, changing climate, and other variables influencing sea level change. However, there is little debate that sea level change could become a major cause of future wetland loss throughout the coastal zone of the United States.

**Figure 7.5.2.2-1: Historic Sea Level Change Trend at Fort Pulaski, Georgia**



Data obtained from: <http://co-ops.nos.noaa.gov/sltrends>

USACE guidance, EC 1165-2-212, titled *Sea-Level Change Considerations for Civil Works Programs*, dated October 1, 2011 outlines a process for estimating local sea level changes for analysis and incorporation into Civil Works Projects. This guidance supersedes the sea level change analysis outlined in the *Planning Guidance Notebook*, ER 1105-2-100 and EC 1165-211. **Figure 7.5.2.2-2** shows the calculations to determine the relative sea level change for Savannah Harbor over the 50 year project life. As shown in **Figure 7.5.2.2-2** and **Figure 7.5.2.2-3**, which are based on the latest USACE guidance: after 50 years the sea level change estimates are 0.5 ft, 0.9 ft, and 2.3 ft, for the low, intermediate and high scenarios, respectively.

**Figure 7.5.2.2-2: Relative Sea Level Change Estimates for SHEP, Based on EC 1165-2-212**

| Eustatic Sea Level Rise                  | Start | Local Land Movement (mm) | b            |
|------------------------------------------|-------|--------------------------|--------------|
| mm/yr                                    | Year  | mm/yr                    | coefficients |
| 1.7                                      | 1992  | 1.28                     | 0.0000271    |
| 8670870 - Fort Pulaski, GA: 2.98 (mm/yr) |       |                          | 0.0000700    |
|                                          |       |                          | 0.0001130    |

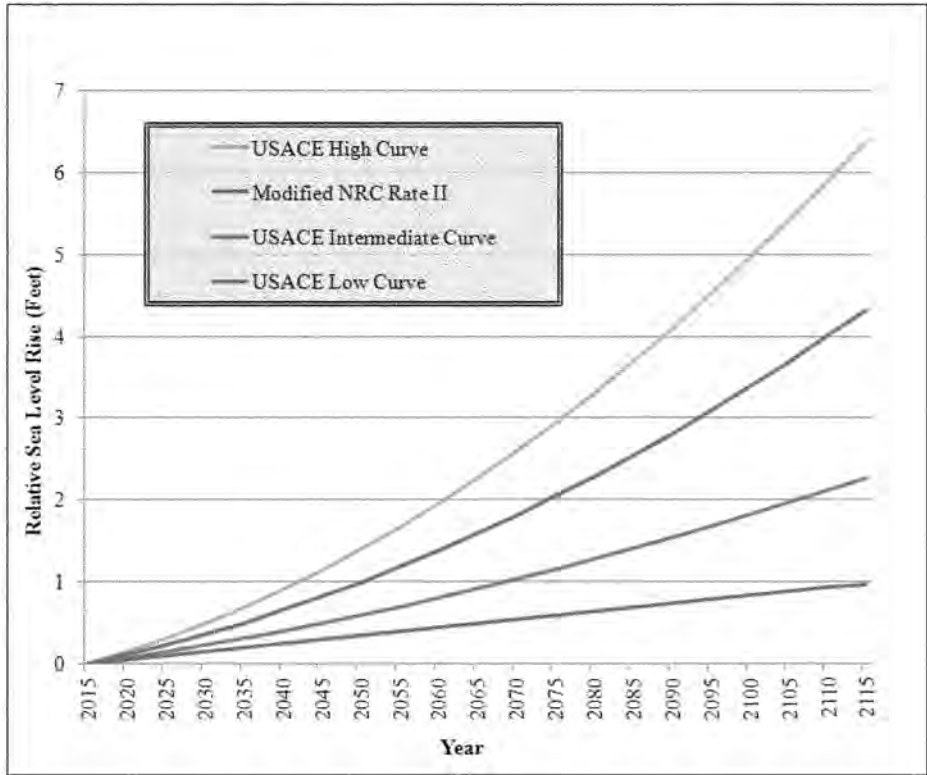
  

| Project |      |      | NTDE  |
|---------|------|------|-------|
| Start   | Life | End  | 83-01 |
| 2015    | 50   | 2065 | 1992  |

| Year        | Sea Level Rise (feet) |             |             |             |
|-------------|-----------------------|-------------|-------------|-------------|
|             | Low                   | Int         | NRC II      | High        |
| 2015        | 0.00                  | 0.00        | 0.00        | 0.00        |
| 2020        | 0.05                  | 0.07        | 0.11        | 0.14        |
| 2025        | 0.10                  | 0.15        | 0.23        | 0.31        |
| 2030        | 0.15                  | 0.23        | 0.36        | 0.49        |
| 2035        | 0.20                  | 0.31        | 0.50        | 0.68        |
| 2040        | 0.24                  | 0.40        | 0.65        | 0.90        |
| 2045        | 0.29                  | 0.50        | 0.82        | 1.14        |
| 2050        | 0.34                  | 0.59        | 0.99        | 1.39        |
| 2055        | 0.39                  | 0.70        | 1.18        | 1.67        |
| 2060        | 0.44                  | 0.80        | 1.38        | 1.96        |
| <b>2065</b> | <b>0.49</b>           | <b>0.92</b> | <b>1.59</b> | <b>2.27</b> |
| 2070        | 0.54                  | 1.03        | 1.81        | 2.60        |
| 2075        | 0.59                  | 1.15        | 2.05        | 2.94        |
| 2080        | 0.64                  | 1.28        | 2.29        | 3.31        |
| 2085        | 0.68                  | 1.41        | 2.55        | 3.69        |
| 2090        | 0.73                  | 1.54        | 2.82        | 4.10        |
| 2095        | 0.78                  | 1.68        | 3.10        | 4.52        |
| 2100        | 0.83                  | 1.82        | 3.39        | 4.96        |
| 2105        | 0.88                  | 1.97        | 3.69        | 5.42        |
| 2110        | 0.93                  | 2.12        | 4.00        | 5.89        |
| 2115        | 0.98                  | 2.28        | 4.33        | 6.39        |

Figure 7.5.2.2-3: Relative Sea Level Change Projection Over Time for SHEP, Based on EC 1165-2-212



In coordination with our Cooperating Agencies and State natural resource agencies, sea level change estimates for alternative analysis with SHEP were determined from the EPA published report titled *The Probability of Sea Level Rise* authored by J. G. Titus and V. K. Narayanan published October 1995. The recommended procedure outlined in the EPA report uses the local historic sea level change trend of a rise of approximately 3 mm/year plus a normalized projection estimate to account for contributions from greenhouse gases, a changing climate, and other factors. The normalized projection estimates the extent and probability to which future sea level rise will exceed what would have happened if the current trends simply continued. For Savannah, over the 50 year life of the project, these estimates ultimately result in a rise in sea level of 25 cm (0.8 ft) and 50 cm (1.6 ft), for the median and 1% high normalized projections. In addition to the two projections, alternatives were evaluated with a sea level rise of 0 ft, which would be the conditions experienced on day-one after project construction. **Table 7.5.2.2-1** shows a comparison of sea level rise estimates using the three methods outlined above.

**Table 7.5.2.2-1: Comparison of Sea Level Rise Estimates**

| Scenario     | Estimate per<br>ER 1105-2-100 | Estimate per<br>EC 1165-2-212 | Estimate per<br>Cooperating<br>Agencies |
|--------------|-------------------------------|-------------------------------|-----------------------------------------|
| Low          | 0.5 ft                        | 0.5 ft                        | n/a                                     |
| Intermediate | n/a                           | 0.9 ft                        | 0.8 ft                                  |
| High         | 2.0 ft                        | 2.3 ft                        | 1.6 ft                                  |

*Estimates based on year-50 of a 50 year project life.*

### 7.5.2.2.1 Impacts to Freshwater Tidal Wetlands Due to Relative Sea Level Change

Impacts to freshwater tidal wetlands/marshes, with various sea level rise estimates, were determined using model simulations and interpolation. **Figure 7.5.2.2.1-1** shows the relationship between sea level rise and the resulting acreage impacts to freshwater tidal wetlands/marshes expected to occur after construction of the deepening project and the flow-altering mitigation plans. This figure is for the 48 ft project depth; however, similar figures were developed to aid analysis for each project depth alternative. The curve shown on this figure enables predictions of the freshwater tidal wetland/marsh impacts for any sea level rise scenario considered in the analysis.

**Table 7.5.2.2.1-1** and **Table 7.5.2.2.1-2** show projected wetland impact acreages using the rates of sea level rise specified in the EC as well as the rates recommended by the SHEP Cooperating Agencies. Projected estimates of wetland impact acreages presented in the tables show continued impact to wetlands, even with flow-altering mitigation, under the historic rate of sea level change. For the 48 ft project depth, these wetland impacts would decline from 337 acres in the base year to 130 acres at the end of the 50-year period of analysis. For all additional estimates of sea level change, ranging from 0.8 to 2.3 ft, at the end of the 50-year project life, there is a net gain in freshwater tidal wetlands/marshes due to implementation of the mitigation plan.

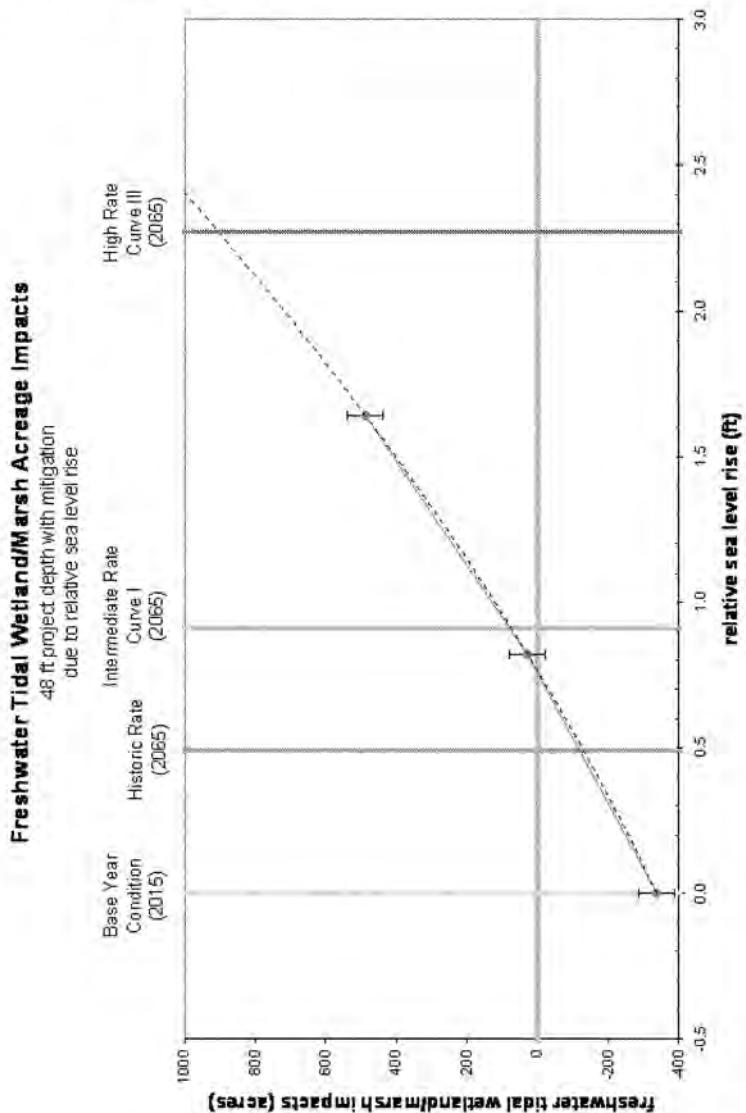
The effects of sea level rise on freshwater marsh impacts over the 50-year project life using the historic rate of sea level rise were calculated using an average annual equivalent calculation methodology and are shown in **Table 7.5.2.2.1-2**. For the 48 ft project depth, the average annual equivalent tidal wetland/marsh impact is -284 acres. When compared to the base year prediction of -337 acres, the difference is approximately 50 acres, which is within the degree of accuracy of the impact predictions. The proposed project would mitigate for the impacts that would occur from the base year. This would ensure the project fully mitigates for impacts it would produce over the entire period of analysis.

The alternative projections of 50-year future sea level rise are presented for information and for comparison. Mitigation requirements are significant at the end of construction but would likely decrease substantially by the end of the 50-year life of the project.

Although the guidance directs design for 50 years in the future, the intention is for the design to be robust and reliable throughout the entire 50-year period of analysis. The marsh mitigation acreage was computed based on conditions expected to occur in the base year when construction is complete. The historic (and most likely future conditions) sea level rise projection is within the limits of error of the modeling and impact determination.

Risk and uncertainties associated with estimates of sea level rise are outlined in greater detail in Section 15.0 of the Engineering Investigations.

Figure 7.5.2.2.1-1: Projected Freshwater Tidal Wetland/Marsh Acreage Impacts (48 ft Project Depth With Mitigation Plan 6a)





**Table 7.5.2.2.1-1: Freshwater Tidal Wetland Acreage Impacts Due to Relative Sea Level Change (Base Year and 50-Year Project Life Projections)**

| Project Depth* | Relative Sea Level Rise (ft)**<br>per EC 1165-2-212 |                      |                                           |                                        |                                            |                                |
|----------------|-----------------------------------------------------|----------------------|-------------------------------------------|----------------------------------------|--------------------------------------------|--------------------------------|
|                | Base Year Condition (2015)                          | Historic Rate (2065) | SHEP Cooperating Agencies Low Rate (2065) | Intermediate Rate EC 1165-2-212 (2065) | SHEP Cooperating Agencies High Rate (2065) | High Rate EC 1165-2-212 (2065) |
|                | 0 ft                                                | 0.5 ft               | 0.8 ft                                    | 0.9 ft                                 | 1.6 ft                                     | 2.3 ft                         |
| 48 ft          | -337                                                | -130                 | 29                                        | 73                                     | 488                                        | 903                            |
| 47 ft          | -223                                                | -86                  | 58                                        | 103                                    | 595                                        | 1181                           |
| 46 ft          | -201                                                | -69                  | 87                                        | 137                                    | 703                                        | 1398                           |
| 45 ft          | -32                                                 | 96                   | 233                                       | 275                                    | 745                                        | 1305                           |
| 44 ft          | 322                                                 | 140                  | 152                                       | 173                                    | 653                                        | 1492                           |

\*All depth alternatives include mitigation features (depths are below MLLW).

\*\*Positive numbers indicate a projected net gain in freshwater wetlands after construction of deepening and flow-altering mitigation. Negative numbers indicate a projected net loss in freshwater wetlands after construction of deepening and flow-altering mitigation.

**Table 7.5.2.2.1-2: Freshwater Tidal Wetland Acreage Impacts Due to Relative Sea Level Change (Project Life Projections Historic Rate of Sea Level Rise)**

| Project Depth* | Historic Rate** |        |        |        |        |        | Average Acreage Impact |
|----------------|-----------------|--------|--------|--------|--------|--------|------------------------|
|                | 2015            | 2025   | 2035   | 2045   | 2055   | 2065   |                        |
|                | Base Year       | 10 yr  | 20 yr  | 30 yr  | 40 yr  | 50 yr  |                        |
|                | 0.0 ft          | 0.1 ft | 0.2 ft | 0.3 ft | 0.4 ft | 0.5 ft |                        |
|                | 0 cm            | 3 cm   | 6 cm   | 9 cm   | 12 cm  | 15 cm  |                        |
| 48 ft          | -337            | -297   | -256   | -214   | -170   | -130   | -234                   |
| 47 ft          | -223            | -202   | -178   | -150   | -118   | -86    | -161                   |
| 46 ft          | -201            | -183   | -161   | -134   | -102   | -69    | -143                   |
| 45 ft          | -32             | -13    | 10     | 36     | 66     | 96     | 26                     |
| 44 ft          | 322             | 265    | 219    | 182    | 155    | 140    | 210                    |

\*All depth alternatives include mitigation features (depths are below MLLW).

\*\*Positive numbers indicate a projected net gain in freshwater wetlands after construction of deepening and flow-altering mitigation. Negative numbers indicate a projected net loss in freshwater wetlands after construction of deepening and flow-altering mitigation.

### 7.5.3 Water Quality & Dissolved Oxygen Mitigation

The previously described, flow-altering mitigation plans do little to mitigate for SHEP impacts to dissolved oxygen (D.O.) levels in the harbor, especially on Front River in the deepened navigation channel. A study prepared for the District titled *Identification and Screening Level Evaluation of Measures to Improve Dissolved Oxygen in the Savannah River Estuary* completed by MACTEC in 2005 identified a D.O. injection system as being the most cost effective method to improve D.O. levels in the harbor. This study is included in the Engineering Investigations Supplemental Materials.

The oxygen injection technology was developed by Dr. Richard Speece. Dr. Speece invented the Speece Cone, a device originally used to add oxygen to the bottom of lakes to enhance downstream fisheries. The Speece Cones are now designed and produced by Eco-Oxygen Technologies, LLC. The Speece Cone technology is a simple process based upon the scientific principle of Henry's Law. No chemicals and no moving parts other than standard municipal wastewater pumps are used. The result is a robust, reliable, economically competitive, and environmentally friendly method. The technology pulls a small sidestream from the river, superoxygenates the water (using pure oxygen), and dilutes it back in the river to satisfy dissolved oxygen deficiencies without treating the entire river. See **Figure 7.5.3-1** for a photo of a Speece Cone.

**Figure 7.5.3-1: Speece Cone Demonstration Project**



Photo from the Georgia Ports Authority demonstration project managed by MACTEC in the summer of 2007. Results of the study are documented in the 2008 MACTEC report titled *Savannah Harbor Reoxygenation Demonstration Project, Savannah, Georgia* which was prepared for the GPA, which is included in the Engineering Investigations Supplemental Materials.

To mitigate for D.O. impacts resulting from SHEP, a plan has been developed to inject superoxygenated water into the estuary using the Speece Cone technology. This mitigation plan was developed by Tetra Tech and results are documented in the report titled *Oxygen Injection Design Report Savannah Harbor Expansion Project* dated October 15, 2010, which is included in the Engineering Investigations Supplemental Materials. After this report was finalized, the D.O. loading amounts to mitigate for SHEP impacts were revised to incorporate effects from flow-altering mitigation features and point source loadings in the harbor. The injection locations identified in the 2010 report did not change, only the required D.O. loadings and number of Speece Cones. Previous analysis excluded the point source loadings to capture D.O. impacts solely due to harbor deepening. However, it was determined that the point source loadings needed to be included in the modeling to capture expected future conditions and ensure that the D.O. mitigation goals were met with the injection system design. **Table 7.5.3-1** shows the mitigation success of the D.O. injection system design for each depth alternative. This summary includes the point source loadings and mitigation features in the model simulations.

**Table 7.5.3-1: Mitigation Success for D.O. Injection System Design (%)**

|                 | Vertical Layer | 44 ft depth | 45 ft depth | 46 ft depth | 47 ft depth | 48 ft depth |
|-----------------|----------------|-------------|-------------|-------------|-------------|-------------|
| 5th percentile  | Surface        | 99.9        | 99.7        | 99.9        | 99.9        | 99.9        |
|                 | Mid-Depth      | 94.4        | 98.3        | 98.1        | 98.7        | 98.5        |
|                 | Bottom         | 97.2        | 97.4        | 97.8        | 98.1        | 97.2        |
|                 | Water Column   | 98.3        | 99.9        | 99.9        | 99.9        | 99.9        |
| 10th percentile | Surface        | 99.9        | 99.9        | 99.8        | 99.9        | 99.9        |
|                 | Mid-Depth      | 95.3        | 99.2        | 99.1        | 99          | 99.1        |
|                 | Bottom         | 97.5        | 97.5        | 97.9        | 98.4        | 97.1        |
|                 | Water Column   | 98.4        | 99.9        | 99.9        | 99.9        | 99.9        |
| 25th percentile | Surface        | 99.9        | 99.9        | 99.9        | 99.9        | 99.9        |
|                 | Mid-Depth      | 95.5        | 99.4        | 99.3        | 99.1        | 99.2        |
|                 | Bottom         | 97.9        | 97.7        | 98          | 98.1        | 97.7        |
|                 | Water Column   | 98.7        | 99.9        | 99.9        | 99.9        | 99.9        |
| 50th percentile | Surface        | 99.9        | 99.9        | 99.9        | 99.9        | 99.9        |
|                 | Mid-Depth      | 96.3        | 97.7        | 97.7        | 98.1        | 97.8        |
|                 | Bottom         | 98          | 98.4        | 97.8        | 97.2        | 97.1        |
|                 | Water Column   | 99.1        | 99.9        | 99.8        | 99.8        | 99.9        |

In developing the D.O. mitigation plan, the same EFDC and WASP hydrodynamic and water quality models approved for use with the project were used. Tetra Tech used these models to determine the amount of oxygen required to mitigate the harbor deepening effects. The results of the modeling study prescribe locations and D.O. loading amounts to mitigate for SHEP impacts for each depth alternative. See **Table 7.5.3-2**.

To calculate the number of Speece Cones required, 4,000 pounds per day was used based on the 80% efficiency (5,000 pounds per day per cone by design). This efficiency percentage was determined from lessons learned after the 2007 demonstration project.

**Table 7.5.3-2: Summary of Dissolved Oxygen Loads for Mitigation**

| Project Depth Alternative | Load (lbs/day) | Total Number of Speece Cones Required* | Location            |                       |                      |
|---------------------------|----------------|----------------------------------------|---------------------|-----------------------|----------------------|
|                           |                |                                        | Near Plant McIntosh | Near IP (Front River) | Near IP (Back River) |
| 44 ft Depth               | 36,000         | 9                                      | 6                   | 1                     | 2                    |
| 45 ft Depth               | 32,000         | 8                                      | 6                   | 1                     | 1                    |
| 46 ft Depth               | 36,000         | 9                                      | 7                   | 1                     | 1                    |
| 47 ft Depth               | 40,000         | 10                                     | 7                   | 2                     | 1                    |
| 48 ft Depth               | 44,000         | 11                                     | 6                   | 4                     | 1                    |

\* One additional Speece Cone will be installed at each site location as a spare for use when maintenance or repairs are required.

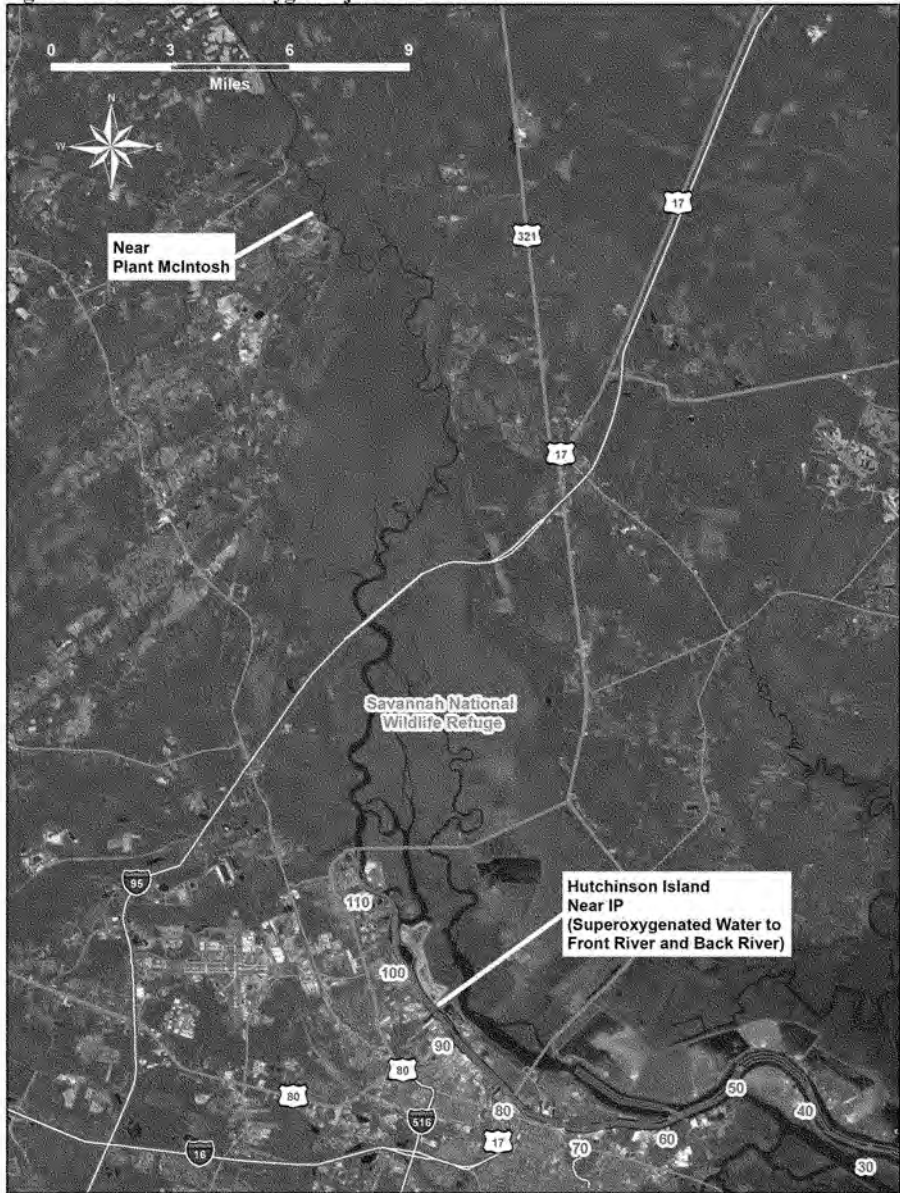
**Figure 7.5.3-2** shows the locations for the proposed D.O. injection systems. For SHEP mitigation two Speece Cone injection locations are required to inject oxygen into the river: 1) Near Plant McIntosh which is in Effingham County, GA upstream of I-95 and 2) Hutchinson Island near International Paper (IP). The Hutchinson Island site has several Speece Cones which are divided, as prescribed by the modeling, to inject superoxygenated water into both Front River and Back River.

In response to questions raised by the South Carolina Department of Health and Environmental Control (DHEC) additional analyses of the oxygen injection systems were conducted. Results of the additional analyses can be found in the report titled *Analysis of Oxygen Injection in the Back River in Support of the Savannah Harbor Expansion Project* prepared by Tetra Tech and Eco Oxygen Technologies dated July 26, 2011 which is included in the Engineering Investigations Supplemental Materials.

Questions raised by DHEC included D.O. system performance concerns in shallow depths on Back River. Hydrographic surveys of the Back River were completed by Savannah District in June 2011 between the tidegate structure and New Cut. The bathymetry showed the depth near the injection location on Back River to be approximately 15 feet below MLLW.

The additional Speece cone research, consultation with the manufacturer, updated bathymetry, revised diffuser design calculations and mixing zone modeling runs conclude that the Speece cones will function as intended on Back River. The analysis concluded that the oxygen plume is readily mixed due to advection and dispersion in the Back River and does not have the potential for effervescent loss.

**Figure 7.5.3-2: Dissolved Oxygen Injection Locations**



Tables 7.5.3-3 through 7.5.3-14 show the D.O. output for the zone averages and critical cells by percentile for existing conditions and each project depth with mitigation (Plan 6a/6b and D.O. injection). For more information on the critical cells and zones see discussion in the previous Section 7.4.3.

**Table 7.5.3-3: Dissolved Oxygen Percentiles for Zones (Existing Conditions)**

| Zone | 1%   | 5%   | 10%  | 25%  | 50%  | 75%  | 90%  | 95%  | 99%  |
|------|------|------|------|------|------|------|------|------|------|
| FR1  | 4.09 | 4.16 | 4.21 | 4.32 | 4.44 | 4.55 | 4.68 | 4.76 | 4.82 |
| FR2  | 3.86 | 3.91 | 3.95 | 4.15 | 4.28 | 4.41 | 4.51 | 4.58 | 4.62 |
| FR3  | 3.58 | 3.66 | 3.72 | 3.88 | 4.06 | 4.25 | 4.52 | 4.60 | 4.81 |
| FR4  | 3.52 | 3.57 | 3.61 | 3.82 | 3.96 | 4.18 | 4.75 | 5.15 | 5.41 |
| FR5  | 3.53 | 3.62 | 3.69 | 3.91 | 4.08 | 4.58 | 5.26 | 5.53 | 5.69 |
| FR6  | 3.79 | 3.83 | 3.92 | 4.13 | 4.36 | 5.04 | 5.69 | 5.86 | 5.97 |
| FR7  | 4.25 | 4.36 | 4.52 | 4.92 | 5.78 | 6.15 | 6.38 | 6.53 | 6.68 |
| FR8  | 4.71 | 4.92 | 5.13 | 5.57 | 6.13 | 6.42 | 6.67 | 6.79 | 6.96 |
| FR9  | 5.60 | 5.87 | 5.99 | 6.24 | 6.53 | 6.80 | 7.05 | 7.21 | 7.33 |
| FR10 | 5.71 | 5.85 | 6.01 | 6.30 | 6.57 | 6.81 | 7.16 | 7.23 | 7.32 |
| FR11 | 4.88 | 5.10 | 5.28 | 5.59 | 5.88 | 6.18 | 6.45 | 6.55 | 6.68 |
| MR1  | 4.29 | 4.41 | 4.55 | 4.79 | 5.06 | 5.47 | 5.77 | 5.89 | 5.99 |
| MR2  | 4.17 | 4.29 | 4.47 | 4.73 | 5.05 | 5.40 | 5.73 | 5.84 | 5.98 |
| MR3  | 3.84 | 4.02 | 4.09 | 4.36 | 4.71 | 5.19 | 5.55 | 5.67 | 5.79 |
| MR4  | 4.38 | 4.50 | 4.60 | 4.77 | 5.04 | 5.23 | 5.43 | 5.53 | 5.69 |
| MR5  | 2.31 | 2.55 | 2.96 | 3.46 | 5.33 | 6.16 | 6.53 | 6.82 | 7.01 |
| MR6  | 2.15 | 2.53 | 3.05 | 3.58 | 5.69 | 6.32 | 6.80 | 6.94 | 7.27 |
| LBR1 | 4.29 | 4.49 | 4.58 | 4.79 | 4.98 | 5.18 | 5.29 | 5.44 | 5.56 |
| LBR2 | 3.69 | 3.80 | 3.95 | 4.13 | 4.35 | 4.55 | 4.70 | 4.76 | 4.89 |
| LBR3 | 3.52 | 3.56 | 3.63 | 3.77 | 3.93 | 4.08 | 4.22 | 4.31 | 4.42 |
| BR1  | 3.42 | 3.47 | 3.52 | 3.77 | 3.90 | 4.06 | 4.24 | 4.32 | 4.42 |
| BR2  | 3.17 | 3.25 | 3.34 | 3.47 | 3.65 | 3.83 | 3.96 | 4.11 | 4.19 |
| BR3  | 3.36 | 3.41 | 3.46 | 3.52 | 3.63 | 3.74 | 3.84 | 3.87 | 3.90 |
| SCh1 | 3.40 | 3.46 | 3.53 | 3.61 | 3.72 | 3.87 | 3.95 | 4.02 | 4.08 |
| SCh2 | 3.84 | 3.94 | 3.99 | 4.11 | 4.26 | 4.38 | 4.48 | 4.53 | 4.63 |
| SR   | 4.90 | 4.95 | 5.18 | 5.52 | 5.84 | 6.17 | 6.35 | 6.41 | 6.48 |
| StbR | 4.73 | 4.91 | 5.07 | 5.39 | 5.75 | 6.06 | 6.25 | 6.38 | 6.54 |

**Table 7.5.3-4: Dissolved Oxygen Percentiles for Zones (44 ft Project with Mitigation Plan 6b and DO Injection)**

| Zone | 1%   | 5%   | 10%  | 25%  | 50%  | 75%  | 90%  | 95%  | 99%  |
|------|------|------|------|------|------|------|------|------|------|
| FR1  | 4.30 | 4.36 | 4.43 | 4.54 | 4.65 | 4.75 | 4.84 | 4.91 | 4.95 |
| FR2  | 4.23 | 4.27 | 4.30 | 4.56 | 4.68 | 4.84 | 4.95 | 5.02 | 5.11 |
| FR3  | 4.08 | 4.15 | 4.21 | 4.46 | 4.59 | 4.77 | 5.11 | 5.23 | 5.44 |
| FR4  | 4.16 | 4.22 | 4.34 | 4.55 | 4.71 | 5.04 | 5.47 | 5.84 | 6.06 |
| FR5  | 4.29 | 4.39 | 4.51 | 4.70 | 4.91 | 5.33 | 5.84 | 6.11 | 6.24 |
| FR6  | 4.40 | 4.49 | 4.65 | 4.84 | 5.13 | 5.62 | 6.18 | 6.33 | 6.46 |
| FR7  | 4.78 | 4.93 | 5.08 | 5.39 | 6.08 | 6.54 | 6.80 | 6.92 | 7.06 |
| FR8  | 5.22 | 5.44 | 5.56 | 5.91 | 6.50 | 6.83 | 7.06 | 7.23 | 7.39 |
| FR9  | 5.89 | 6.15 | 6.33 | 6.61 | 6.90 | 7.17 | 7.46 | 7.65 | 7.80 |
| FR10 | 6.44 | 6.52 | 6.66 | 6.96 | 7.19 | 7.47 | 7.85 | 7.98 | 8.16 |
| FR11 | 6.41 | 6.49 | 6.61 | 6.97 | 7.17 | 7.43 | 7.88 | 8.02 | 8.15 |
| MR1  | 5.05 | 5.17 | 5.25 | 5.49 | 5.79 | 6.08 | 6.26 | 6.36 | 6.44 |
| MR2  | 5.16 | 5.29 | 5.40 | 5.61 | 5.88 | 6.10 | 6.26 | 6.35 | 6.46 |
| MR3  | 5.26 | 5.38 | 5.49 | 5.72 | 5.96 | 6.22 | 6.36 | 6.44 | 6.50 |
| MR4  | 5.62 | 5.76 | 5.87 | 6.04 | 6.30 | 6.58 | 6.83 | 6.99 | 7.15 |
| MR5  | 4.38 | 4.68 | 4.99 | 5.40 | 6.60 | 7.27 | 7.71 | 7.93 | 8.05 |
| MR6  | 6.10 | 6.29 | 6.39 | 6.59 | 6.78 | 6.94 | 7.16 | 7.28 | 7.39 |
| LBR1 | 5.46 | 5.72 | 5.79 | 6.00 | 6.19 | 6.39 | 6.70 | 6.82 | 6.90 |
| LBR2 | 5.19 | 5.29 | 5.37 | 5.55 | 5.75 | 5.94 | 6.14 | 6.29 | 6.40 |
| LBR3 | 3.95 | 4.09 | 4.21 | 4.45 | 4.78 | 5.10 | 5.32 | 5.41 | 5.57 |
| BR1  | 4.32 | 4.40 | 4.47 | 4.59 | 4.77 | 5.01 | 5.11 | 5.18 | 5.27 |
| BR2  | 4.25 | 4.35 | 4.43 | 4.57 | 4.73 | 4.89 | 5.03 | 5.11 | 5.20 |
| BR3  | 3.53 | 3.62 | 3.69 | 3.84 | 4.00 | 4.19 | 4.32 | 4.41 | 4.53 |
| SCh1 | 4.01 | 4.09 | 4.14 | 4.24 | 4.32 | 4.43 | 4.53 | 4.58 | 4.66 |
| SCh2 | 4.37 | 4.44 | 4.51 | 4.67 | 4.81 | 4.92 | 5.02 | 5.08 | 5.18 |
| SR   | 7.26 | 7.38 | 7.49 | 7.85 | 8.11 | 8.30 | 9.07 | 9.17 | 9.29 |
| StbR | 5.44 | 5.62 | 5.74 | 6.04 | 6.34 | 6.58 | 6.76 | 6.86 | 7.02 |



**Table 7.5.3-5: Dissolved Oxygen Percentiles for Zones (45 ft Project with Mitigation Plan 6a and DO Injection)**

| Zone | 1%   | 5%   | 10%  | 25%  | 50%  | 75%  | 90%  | 95%  | 99%  |
|------|------|------|------|------|------|------|------|------|------|
| FR1  | 4.30 | 4.36 | 4.42 | 4.52 | 4.64 | 4.73 | 4.82 | 4.86 | 4.92 |
| FR2  | 4.23 | 4.27 | 4.30 | 4.52 | 4.64 | 4.81 | 4.91 | 4.97 | 5.04 |
| FR3  | 4.07 | 4.14 | 4.20 | 4.42 | 4.54 | 4.73 | 5.03 | 5.13 | 5.30 |
| FR4  | 4.15 | 4.20 | 4.31 | 4.51 | 4.67 | 4.97 | 5.36 | 5.69 | 5.94 |
| FR5  | 4.26 | 4.36 | 4.48 | 4.66 | 4.84 | 5.25 | 5.68 | 5.99 | 6.13 |
| FR6  | 4.37 | 4.46 | 4.61 | 4.78 | 5.03 | 5.50 | 6.05 | 6.25 | 6.39 |
| FR7  | 4.71 | 4.86 | 5.01 | 5.29 | 5.97 | 6.47 | 6.73 | 6.86 | 6.97 |
| FR8  | 5.12 | 5.34 | 5.44 | 5.79 | 6.41 | 6.80 | 7.01 | 7.17 | 7.37 |
| FR9  | 5.77 | 6.05 | 6.20 | 6.50 | 6.85 | 7.14 | 7.42 | 7.64 | 7.80 |
| FR10 | 6.44 | 6.53 | 6.65 | 6.95 | 7.18 | 7.46 | 7.84 | 7.96 | 8.14 |
| FR11 | 6.41 | 6.49 | 6.61 | 6.96 | 7.17 | 7.42 | 7.88 | 8.02 | 8.15 |
| MR1  | 4.98 | 5.12 | 5.22 | 5.44 | 5.78 | 6.04 | 6.22 | 6.30 | 6.39 |
| MR2  | 5.18 | 5.30 | 5.42 | 5.63 | 5.86 | 6.10 | 6.24 | 6.29 | 6.42 |
| MR3  | 5.39 | 5.49 | 5.57 | 5.82 | 6.07 | 6.30 | 6.43 | 6.50 | 6.63 |
| MR4  | 5.74 | 5.92 | 6.01 | 6.20 | 6.47 | 6.76 | 7.02 | 7.19 | 7.33 |
| MR5  | 5.04 | 5.40 | 5.64 | 5.94 | 6.74 | 7.28 | 7.74 | 7.92 | 8.05 |
| MR6  | 4.14 | 4.38 | 4.52 | 4.74 | 5.13 | 5.48 | 5.65 | 5.79 | 5.97 |
| LBR1 | 5.70 | 5.93 | 6.04 | 6.24 | 6.46 | 6.71 | 7.00 | 7.15 | 7.25 |
| LBR2 | 5.49 | 5.57 | 5.67 | 5.88 | 6.09 | 6.29 | 6.51 | 6.62 | 6.75 |
| LBR3 | 4.57 | 4.74 | 4.84 | 5.03 | 5.28 | 5.55 | 5.74 | 5.85 | 6.03 |
| BR1  | 3.85 | 4.09 | 4.21 | 4.46 | 4.68 | 4.92 | 5.06 | 5.11 | 5.22 |
| BR2  | 3.75 | 3.86 | 3.91 | 4.04 | 4.24 | 4.53 | 4.76 | 4.84 | 4.96 |
| BR3  | 3.74 | 3.82 | 3.85 | 3.93 | 4.05 | 4.20 | 4.35 | 4.45 | 4.55 |
| SCh1 | 3.97 | 4.06 | 4.12 | 4.22 | 4.30 | 4.41 | 4.49 | 4.55 | 4.63 |
| SCh2 | 4.36 | 4.42 | 4.49 | 4.64 | 4.78 | 4.89 | 4.98 | 5.03 | 5.13 |
| SR   | 7.26 | 7.38 | 7.49 | 7.85 | 8.11 | 8.30 | 9.08 | 9.17 | 9.29 |
| StbR | 5.47 | 5.63 | 5.72 | 6.00 | 6.30 | 6.54 | 6.70 | 6.79 | 6.98 |



**Table 7.5.3-6: Dissolved Oxygen Percentiles for Zones (46 ft Project with Mitigation Plan 6a and DO Injection)**

| Zone | 1%   | 5%   | 10%  | 25%  | 50%  | 75%  | 90%  | 95%  | 99%  |
|------|------|------|------|------|------|------|------|------|------|
| FR1  | 4.31 | 4.36 | 4.42 | 4.52 | 4.65 | 4.74 | 4.82 | 4.87 | 4.92 |
| FR2  | 4.23 | 4.26 | 4.29 | 4.53 | 4.64 | 4.81 | 4.91 | 4.96 | 5.04 |
| FR3  | 4.09 | 4.14 | 4.19 | 4.42 | 4.55 | 4.72 | 5.01 | 5.09 | 5.21 |
| FR4  | 4.15 | 4.20 | 4.32 | 4.51 | 4.66 | 4.94 | 5.27 | 5.57 | 5.84 |
| FR5  | 4.26 | 4.35 | 4.48 | 4.65 | 4.83 | 5.19 | 5.56 | 5.89 | 6.08 |
| FR6  | 4.36 | 4.45 | 4.60 | 4.76 | 5.01 | 5.41 | 5.95 | 6.20 | 6.37 |
| FR7  | 4.70 | 4.85 | 4.98 | 5.25 | 5.90 | 6.44 | 6.73 | 6.86 | 6.98 |
| FR8  | 5.12 | 5.32 | 5.43 | 5.74 | 6.39 | 6.81 | 7.06 | 7.18 | 7.39 |
| FR9  | 5.75 | 6.02 | 6.17 | 6.51 | 6.88 | 7.17 | 7.42 | 7.69 | 7.85 |
| FR10 | 6.53 | 6.63 | 6.75 | 7.04 | 7.28 | 7.57 | 7.93 | 8.12 | 8.27 |
| FR11 | 6.57 | 6.67 | 6.79 | 7.12 | 7.35 | 7.58 | 8.08 | 8.23 | 8.36 |
| MR1  | 4.98 | 5.11 | 5.23 | 5.44 | 5.81 | 6.07 | 6.25 | 6.32 | 6.41 |
| MR2  | 5.18 | 5.31 | 5.44 | 5.66 | 5.89 | 6.15 | 6.27 | 6.33 | 6.43 |
| MR3  | 5.45 | 5.58 | 5.65 | 5.90 | 6.15 | 6.35 | 6.50 | 6.58 | 6.73 |
| MR4  | 5.83 | 6.03 | 6.12 | 6.31 | 6.59 | 6.87 | 7.15 | 7.32 | 7.48 |
| MR5  | 5.15 | 5.53 | 5.76 | 6.08 | 6.91 | 7.43 | 7.88 | 8.08 | 8.25 |
| MR6  | 4.15 | 4.40 | 4.53 | 4.76 | 5.14 | 5.50 | 5.68 | 5.82 | 6.01 |
| LBR1 | 5.85 | 6.05 | 6.16 | 6.37 | 6.59 | 6.85 | 7.14 | 7.28 | 7.38 |
| LBR2 | 5.61 | 5.69 | 5.79 | 5.99 | 6.20 | 6.41 | 6.65 | 6.76 | 6.87 |
| LBR3 | 4.67 | 4.84 | 4.95 | 5.13 | 5.39 | 5.65 | 5.86 | 5.97 | 6.13 |
| BR1  | 3.91 | 4.14 | 4.25 | 4.50 | 4.70 | 4.93 | 5.08 | 5.12 | 5.22 |
| BR2  | 3.83 | 3.93 | 3.99 | 4.10 | 4.30 | 4.56 | 4.79 | 4.88 | 5.00 |
| BR3  | 3.82 | 3.89 | 3.94 | 4.00 | 4.13 | 4.28 | 4.43 | 4.55 | 4.63 |
| SCh1 | 4.02 | 4.09 | 4.15 | 4.24 | 4.33 | 4.42 | 4.50 | 4.55 | 4.62 |
| SCh2 | 4.36 | 4.42 | 4.49 | 4.65 | 4.79 | 4.90 | 4.99 | 5.04 | 5.14 |
| SR   | 7.51 | 7.63 | 7.74 | 8.09 | 8.36 | 8.57 | 9.36 | 9.47 | 9.60 |
| StbR | 5.51 | 5.69 | 5.77 | 6.04 | 6.34 | 6.56 | 6.72 | 6.79 | 6.97 |

**Table 7.5.3-7: Dissolved Oxygen Percentiles for Zones (47 ft Project with Mitigation Plan 6a and DO Injection)**

| <b>Zone</b> | <b>1%</b> | <b>5%</b> | <b>10%</b> | <b>25%</b> | <b>50%</b> | <b>75%</b> | <b>90%</b> | <b>95%</b> | <b>99%</b> |
|-------------|-----------|-----------|------------|------------|------------|------------|------------|------------|------------|
| FR1         | 4.34      | 4.39      | 4.45       | 4.56       | 4.64       | 4.74       | 4.83       | 4.88       | 4.94       |
| FR2         | 4.27      | 4.30      | 4.33       | 4.55       | 4.65       | 4.82       | 4.92       | 4.97       | 5.04       |
| FR3         | 4.13      | 4.19      | 4.23       | 4.44       | 4.55       | 4.74       | 5.01       | 5.08       | 5.20       |
| FR4         | 4.21      | 4.28      | 4.39       | 4.57       | 4.76       | 5.04       | 5.34       | 5.67       | 5.90       |
| FR5         | 4.37      | 4.47      | 4.59       | 4.73       | 4.95       | 5.28       | 5.61       | 5.87       | 6.05       |
| FR6         | 4.50      | 4.59      | 4.73       | 4.86       | 5.09       | 5.44       | 5.90       | 6.15       | 6.33       |
| FR7         | 4.80      | 4.93      | 5.05       | 5.31       | 5.86       | 6.38       | 6.70       | 6.85       | 6.95       |
| FR8         | 5.19      | 5.37      | 5.45       | 5.76       | 6.34       | 6.79       | 7.04       | 7.16       | 7.34       |
| FR9         | 5.73      | 5.99      | 6.13       | 6.49       | 6.85       | 7.15       | 7.41       | 7.64       | 7.82       |
| FR10        | 6.54      | 6.63      | 6.74       | 7.05       | 7.28       | 7.57       | 7.94       | 8.11       | 8.28       |
| FR11        | 6.57      | 6.67      | 6.79       | 7.12       | 7.35       | 7.58       | 8.08       | 8.23       | 8.36       |
| MR1         | 5.05      | 5.20      | 5.28       | 5.47       | 5.81       | 6.04       | 6.22       | 6.29       | 6.38       |
| MR2         | 5.22      | 5.33      | 5.45       | 5.67       | 5.88       | 6.12       | 6.25       | 6.34       | 6.40       |
| MR3         | 5.44      | 5.58      | 5.65       | 5.89       | 6.14       | 6.35       | 6.50       | 6.57       | 6.74       |
| MR4         | 5.85      | 6.03      | 6.12       | 6.31       | 6.59       | 6.87       | 7.16       | 7.34       | 7.47       |
| MR5         | 5.16      | 5.53      | 5.76       | 6.09       | 6.90       | 7.42       | 7.89       | 8.08       | 8.25       |
| MR6         | 4.14      | 4.40      | 4.54       | 4.75       | 5.14       | 5.50       | 5.68       | 5.82       | 6.01       |
| LBR1        | 5.85      | 6.05      | 6.17       | 6.37       | 6.60       | 6.85       | 7.14       | 7.28       | 7.38       |
| LBR2        | 5.61      | 5.69      | 5.79       | 5.99       | 6.19       | 6.40       | 6.64       | 6.74       | 6.91       |
| LBR3        | 4.66      | 4.83      | 4.94       | 5.13       | 5.39       | 5.64       | 5.85       | 5.97       | 6.14       |
| BR1         | 3.97      | 4.21      | 4.34       | 4.54       | 4.73       | 4.96       | 5.08       | 5.14       | 5.25       |
| BR2         | 3.89      | 4.00      | 4.03       | 4.16       | 4.36       | 4.64       | 4.85       | 4.94       | 5.08       |
| BR3         | 3.85      | 3.93      | 3.96       | 4.04       | 4.14       | 4.30       | 4.43       | 4.54       | 4.63       |
| SCh1        | 4.02      | 4.09      | 4.14       | 4.25       | 4.33       | 4.41       | 4.50       | 4.56       | 4.61       |
| SCh2        | 4.39      | 4.45      | 4.51       | 4.66       | 4.79       | 4.89       | 5.00       | 5.04       | 5.13       |
| SR          | 7.51      | 7.63      | 7.75       | 8.09       | 8.36       | 8.57       | 9.36       | 9.47       | 9.60       |
| StbR        | 5.49      | 5.68      | 5.76       | 6.03       | 6.31       | 6.54       | 6.72       | 6.78       | 6.95       |

**Table 7.5.3-8: Dissolved Oxygen Percentiles for Zones (48 ft Project with Mitigation Plan 6a and DO Injection)**

| <b>Zone</b> | <b>1%</b> | <b>5%</b> | <b>10%</b> | <b>25%</b> | <b>50%</b> | <b>75%</b> | <b>90%</b> | <b>95%</b> | <b>99%</b> |
|-------------|-----------|-----------|------------|------------|------------|------------|------------|------------|------------|
| FR1         | 4.32      | 4.38      | 4.43       | 4.58       | 4.67       | 4.75       | 4.83       | 4.90       | 4.96       |
| FR2         | 4.26      | 4.29      | 4.32       | 4.57       | 4.67       | 4.83       | 4.94       | 5.00       | 5.07       |
| FR3         | 4.15      | 4.20      | 4.23       | 4.48       | 4.61       | 4.76       | 5.03       | 5.12       | 5.26       |
| FR4         | 4.24      | 4.36      | 4.49       | 4.68       | 4.94       | 5.28       | 5.62       | 5.85       | 6.09       |
| FR5         | 4.48      | 4.60      | 4.76       | 4.90       | 5.17       | 5.50       | 5.82       | 5.94       | 6.25       |
| FR6         | 4.74      | 4.83      | 4.94       | 5.07       | 5.29       | 5.56       | 5.97       | 6.14       | 6.30       |
| FR7         | 4.96      | 5.08      | 5.21       | 5.45       | 5.89       | 6.34       | 6.65       | 6.78       | 6.89       |
| FR8         | 5.30      | 5.45      | 5.53       | 5.80       | 6.28       | 6.73       | 6.96       | 7.10       | 7.27       |
| FR9         | 5.73      | 5.95      | 6.11       | 6.41       | 6.77       | 7.07       | 7.32       | 7.55       | 7.72       |
| FR10        | 6.44      | 6.54      | 6.65       | 6.95       | 7.18       | 7.45       | 7.82       | 7.97       | 8.14       |
| FR11        | 6.42      | 6.50      | 6.61       | 6.96       | 7.17       | 7.42       | 7.88       | 8.02       | 8.15       |
| MR1         | 5.18      | 5.28      | 5.37       | 5.54       | 5.81       | 6.01       | 6.18       | 6.25       | 6.35       |
| MR2         | 5.23      | 5.32      | 5.43       | 5.67       | 5.87       | 6.07       | 6.19       | 6.30       | 6.37       |
| MR3         | 5.38      | 5.49      | 5.57       | 5.82       | 6.06       | 6.28       | 6.41       | 6.48       | 6.65       |
| MR4         | 5.74      | 5.93      | 6.03       | 6.22       | 6.48       | 6.76       | 7.04       | 7.21       | 7.34       |
| MR5         | 5.03      | 5.40      | 5.64       | 5.97       | 6.76       | 7.28       | 7.74       | 7.93       | 8.06       |
| MR6         | 4.12      | 4.38      | 4.52       | 4.74       | 5.13       | 5.48       | 5.65       | 5.79       | 5.96       |
| LBR1        | 5.73      | 5.92      | 6.04       | 6.25       | 6.48       | 6.72       | 7.01       | 7.16       | 7.26       |
| LBR2        | 5.50      | 5.57      | 5.67       | 5.88       | 6.08       | 6.30       | 6.52       | 6.62       | 6.70       |
| LBR3        | 4.54      | 4.71      | 4.82       | 5.01       | 5.27       | 5.54       | 5.74       | 5.82       | 6.02       |
| BR1         | 4.03      | 4.26      | 4.39       | 4.58       | 4.78       | 5.01       | 5.14       | 5.18       | 5.27       |
| BR2         | 3.92      | 4.01      | 4.05       | 4.18       | 4.40       | 4.67       | 4.91       | 4.98       | 5.11       |
| BR3         | 3.78      | 3.89      | 3.92       | 3.98       | 4.10       | 4.24       | 4.35       | 4.45       | 4.54       |
| SCh1        | 4.02      | 4.08      | 4.14       | 4.27       | 4.37       | 4.46       | 4.53       | 4.57       | 4.65       |
| SCh2        | 4.38      | 4.45      | 4.50       | 4.68       | 4.81       | 4.92       | 5.01       | 5.05       | 5.14       |
| SR          | 7.26      | 7.38      | 7.49       | 7.85       | 8.11       | 8.30       | 9.07       | 9.17       | 9.29       |
| SibR        | 5.39      | 5.62      | 5.73       | 5.99       | 6.27       | 6.48       | 6.64       | 6.72       | 6.86       |

**Table 7.5.3-9: Dissolved Oxygen Percentiles for Critical Cells (Existing Conditions)**

| Zone | 1%   | 5%   | 10%  | 25%  | 50%  | 75%  | 90%  | 95%  | 99%  | Critical Cell*   |
|------|------|------|------|------|------|------|------|------|------|------------------|
| FR1  | 3.86 | 3.93 | 3.99 | 4.13 | 4.30 | 4.43 | 4.56 | 4.62 | 4.69 | I= 13 J= 40 K= 6 |
| FR2  | 3.56 | 3.66 | 3.74 | 3.91 | 4.10 | 4.28 | 4.46 | 4.52 | 4.91 | I= 15 J= 52 K= 6 |
| FR3  | 3.36 | 3.47 | 3.50 | 3.71 | 3.90 | 4.14 | 4.59 | 4.90 | 5.48 | I= 15 J= 57 K= 6 |
| FR4  | 3.34 | 3.43 | 3.49 | 3.74 | 3.91 | 4.23 | 4.78 | 5.14 | 5.36 | I= 15 J= 60 K= 6 |
| FR5  | 3.45 | 3.55 | 3.68 | 3.88 | 4.10 | 4.70 | 5.26 | 5.51 | 5.68 | I= 15 J= 67 K= 6 |
| FR6  | 3.55 | 3.66 | 3.78 | 3.95 | 4.19 | 4.80 | 5.55 | 5.78 | 5.95 | I= 13 J= 73 K= 6 |
| FR7  | 3.98 | 4.06 | 4.14 | 4.40 | 4.86 | 5.93 | 6.22 | 6.34 | 6.48 | I= 14 J= 81 K= 6 |
| FR8  | 4.48 | 4.62 | 4.90 | 5.41 | 6.09 | 6.43 | 6.71 | 6.83 | 7.11 | I= 14 J= 94 K= 6 |
| FR9  | 4.72 | 4.87 | 5.22 | 5.62 | 6.24 | 6.57 | 6.83 | 6.99 | 7.18 | I= 14 J= 98 K= 6 |
| FR10 | 4.31 | 4.78 | 4.95 | 5.32 | 5.91 | 6.43 | 6.68 | 7.01 | 7.21 | I= 15 J=120 K= 6 |
| FR11 | 4.17 | 4.70 | 4.93 | 5.24 | 5.66 | 6.14 | 6.49 | 6.64 | 7.13 | I= 14 J=123 K= 6 |
| MR1  | 4.22 | 4.34 | 4.47 | 4.72 | 5.05 | 5.51 | 5.81 | 5.93 | 6.19 | I= 17 J= 82 K= 6 |
| MR2  | 4.01 | 4.13 | 4.30 | 4.60 | 5.02 | 5.47 | 5.73 | 5.84 | 5.98 | I= 21 J= 86 K= 6 |
| MR3  | 3.68 | 3.88 | 3.94 | 4.16 | 4.47 | 4.95 | 5.66 | 5.93 | 6.28 | I= 26 J= 98 K= 6 |
| MR4  | 3.87 | 4.02 | 4.11 | 4.37 | 4.59 | 4.87 | 5.04 | 5.15 | 5.39 | I= 26 J=105 K= 6 |
| MR5  | 1.49 | 2.04 | 2.41 | 3.05 | 4.97 | 6.23 | 6.56 | 6.89 | 7.11 | I= 22 J=123 K= 6 |
| MR6  | 2.11 | 2.49 | 3.01 | 3.51 | 5.61 | 6.35 | 6.80 | 7.06 | 7.32 | I= 20 J=119 K= 6 |
| LBR1 | 3.57 | 4.35 | 4.74 | 5.12 | 5.42 | 5.64 | 5.97 | 6.15 | 6.47 | I= 27 J=123 K= 6 |
| LBR2 | 3.68 | 3.86 | 3.97 | 4.15 | 4.38 | 4.59 | 4.77 | 4.86 | 5.24 | I= 39 J=113 K= 6 |
| LBR3 | 2.88 | 3.28 | 3.46 | 3.67 | 3.92 | 4.31 | 4.70 | 4.95 | 5.18 | I= 30 J= 92 K= 6 |
| BR1  | 3.15 | 3.28 | 3.44 | 3.59 | 3.82 | 4.05 | 4.26 | 4.34 | 4.45 | I= 31 J= 63 K= 6 |
| BR2  | 2.43 | 2.72 | 2.86 | 3.11 | 3.30 | 3.54 | 3.67 | 3.74 | 3.82 | I= 33 J= 70 K= 6 |
| BR3  | 2.87 | 3.12 | 3.32 | 3.48 | 3.65 | 3.80 | 3.93 | 4.00 | 4.13 | I= 32 J= 72 K= 6 |
| SCh1 | 2.25 | 2.41 | 2.53 | 2.68 | 2.88 | 3.30 | 3.69 | 3.80 | 4.08 | I= 10 J= 24 K= 6 |
| SCh2 | 3.62 | 3.78 | 3.88 | 4.02 | 4.19 | 4.35 | 4.48 | 4.56 | 4.70 | I= 7 J= 46 K= 6  |
| SR   | 4.69 | 4.74 | 4.97 | 5.31 | 5.62 | 5.97 | 6.11 | 6.16 | 6.23 | I= 14 J=140 K= 6 |
| SthR | 3.83 | 4.19 | 4.53 | 5.01 | 5.66 | 6.16 | 6.47 | 6.62 | 6.81 | I= 23 J=101 K= 6 |

\* The critical cell is the cell with lowest D.O. concentration within a Zone. Surface Layer K= 1; Bottom Layer K=6.

**Table 7.5.3-10: Dissolved Oxygen Percentiles for Critical Cells (44 ft Project with Mitigation Plan 6b and DO Injection)**

| Zone | 1%   | 5%   | 10%  | 25%  | 50%  | 75%  | 90%  | 95%  | 99%  | Critical Cell*   |
|------|------|------|------|------|------|------|------|------|------|------------------|
| FR1  | 3.96 | 4.05 | 4.11 | 4.30 | 4.43 | 4.60 | 4.70 | 4.73 | 4.77 | I= 13 J= 38 K= 6 |
| FR2  | 3.82 | 3.92 | 4.00 | 4.25 | 4.41 | 4.59 | 4.86 | 4.95 | 5.03 | I= 15 J= 52 K= 6 |
| FR3  | 3.70 | 3.77 | 3.87 | 4.13 | 4.31 | 4.60 | 5.16 | 5.64 | 6.02 | I= 15 J= 59 K= 6 |
| FR4  | 3.72 | 3.80 | 3.90 | 4.18 | 4.33 | 4.67 | 5.22 | 5.61 | 5.94 | I= 15 J= 60 K= 6 |
| FR5  | 4.01 | 4.12 | 4.30 | 4.46 | 4.66 | 5.04 | 5.75 | 5.98 | 6.18 | I= 14 J= 70 K= 6 |
| FR6  | 4.07 | 4.15 | 4.26 | 4.47 | 4.63 | 5.01 | 5.74 | 6.03 | 6.15 | I= 14 J= 73 K= 6 |
| FR7  | 4.43 | 4.51 | 4.58 | 4.81 | 5.10 | 6.08 | 6.49 | 6.65 | 6.78 | I= 14 J= 81 K= 6 |
| FR8  | 4.83 | 4.93 | 5.10 | 5.50 | 6.35 | 6.69 | 6.92 | 7.05 | 7.27 | I= 14 J= 94 K= 6 |
| FR9  | 5.03 | 5.14 | 5.37 | 5.74 | 6.52 | 6.93 | 7.19 | 7.31 | 7.51 | I= 14 J= 99 K= 6 |
| FR10 | 6.18 | 6.39 | 6.53 | 6.86 | 7.08 | 7.33 | 7.78 | 7.87 | 7.95 | I= 13 J=120 K= 4 |
| FR11 | 2.71 | 2.71 | 2.72 | 2.74 | 2.78 | 2.89 | 3.03 | 3.11 | 3.18 | I= 14 J=122 K= 5 |
| MR1  | 4.78 | 4.90 | 4.99 | 5.17 | 5.43 | 5.77 | 6.14 | 6.31 | 6.57 | I= 17 J= 82 K= 6 |
| MR2  | 4.70 | 4.84 | 4.94 | 5.18 | 5.47 | 5.80 | 6.07 | 6.18 | 6.29 | I= 21 J= 86 K= 6 |
| MR3  | 4.64 | 4.82 | 4.94 | 5.13 | 5.44 | 5.71 | 5.99 | 6.12 | 6.28 | I= 26 J= 94 K= 6 |
| MR4  | 4.80 | 5.49 | 5.66 | 5.97 | 6.26 | 6.67 | 7.03 | 7.28 | 7.80 | I= 26 J=122 K= 6 |
| MR5  | 2.45 | 2.66 | 2.93 | 3.64 | 6.55 | 7.36 | 7.81 | 7.97 | 8.08 | I= 22 J=123 K= 6 |
| MR6  | 5.82 | 6.17 | 6.35 | 6.62 | 6.88 | 7.10 | 7.35 | 7.41 | 7.67 | I= 20 J=119 K= 6 |
| LBR1 | 4.09 | 5.07 | 5.76 | 6.10 | 6.39 | 6.76 | 7.10 | 7.30 | 7.81 | I= 27 J=123 K= 6 |
| LBR2 | 4.09 | 4.87 | 4.95 | 5.18 | 5.38 | 5.61 | 5.82 | 6.03 | 6.47 | I= 39 J=113 K= 6 |
| LBR3 | 2.64 | 2.75 | 2.84 | 3.07 | 3.35 | 3.73 | 3.97 | 4.11 | 4.21 | I= 30 J= 86 K= 6 |
| BR1  | 3.72 | 3.98 | 4.16 | 4.30 | 4.49 | 4.68 | 4.82 | 4.89 | 4.98 | I= 32 J= 62 K= 6 |
| BR2  | 2.94 | 3.20 | 3.45 | 3.79 | 4.11 | 4.37 | 4.50 | 4.58 | 4.73 | I= 33 J= 65 K= 6 |
| BR3  | 2.59 | 2.72 | 2.80 | 3.01 | 3.90 | 5.11 | 5.54 | 5.71 | 5.86 | I= 30 J= 76 K= 6 |
| SCh1 | 2.38 | 2.68 | 2.81 | 2.97 | 3.30 | 4.14 | 4.41 | 4.50 | 4.72 | I= 10 J= 23 K= 6 |
| SCh2 | 3.88 | 4.01 | 4.11 | 4.23 | 4.43 | 4.58 | 4.69 | 4.79 | 4.93 | I= 7 J= 46 K= 6  |
| SR   | 6.14 | 6.25 | 6.46 | 6.83 | 7.06 | 7.34 | 7.81 | 7.91 | 8.01 | I= 13 J=128 K= 4 |
| StbR | 4.06 | 4.80 | 5.02 | 5.57 | 6.14 | 6.56 | 6.81 | 7.03 | 7.18 | I= 21 J=101 K= 6 |

\* The critical cell is the cell with lowest D.O. concentration within a Zone. Surface Layer K=1; Bottom Layer K=6.

**Table 7.5.3-11: Dissolved Oxygen Percentiles for Critical Cells (45 ft Project with Mitigation Plan 6a and DO Injection)**

| Zone | 1%   | 5%   | 10%  | 25%  | 50%  | 75%  | 90%  | 95%  | 99%  | Critical Cell*   |
|------|------|------|------|------|------|------|------|------|------|------------------|
| FR1  | 3.97 | 4.03 | 4.08 | 4.26 | 4.40 | 4.57 | 4.68 | 4.72 | 4.78 | I= 13 J= 39 K= 6 |
| FR2  | 3.81 | 3.89 | 3.97 | 4.21 | 4.36 | 4.54 | 4.77 | 4.88 | 4.93 | I= 15 J= 52 K= 6 |
| FR3  | 3.70 | 3.77 | 3.86 | 4.11 | 4.26 | 4.54 | 5.06 | 5.62 | 5.95 | I= 15 J= 59 K= 6 |
| FR4  | 3.73 | 3.78 | 3.89 | 4.14 | 4.29 | 4.61 | 5.14 | 5.56 | 5.99 | I= 15 J= 60 K= 6 |
| FR5  | 4.03 | 4.26 | 4.42 | 4.60 | 4.94 | 5.39 | 5.73 | 6.01 | 6.26 | I= 13 J= 67 K= 5 |
| FR6  | 4.07 | 4.11 | 4.23 | 4.43 | 4.57 | 4.91 | 5.59 | 5.90 | 6.05 | I= 14 J= 73 K= 6 |
| FR7  | 4.79 | 4.89 | 5.04 | 5.32 | 5.88 | 6.40 | 6.69 | 6.85 | 7.50 | I= 15 J= 86 K= 6 |
| FR8  | 4.79 | 4.91 | 5.15 | 5.45 | 6.39 | 6.82 | 7.07 | 7.18 | 7.39 | I= 14 J= 94 K= 5 |
| FR9  | 4.93 | 5.05 | 5.23 | 5.58 | 6.32 | 6.82 | 7.07 | 7.17 | 7.47 | I= 14 J= 98 K= 6 |
| FR10 | 6.18 | 6.36 | 6.52 | 6.84 | 7.07 | 7.34 | 7.78 | 7.85 | 7.97 | I= 13 J=119 K= 4 |
| FR11 | 2.71 | 2.71 | 2.72 | 2.74 | 2.78 | 2.89 | 3.03 | 3.11 | 3.18 | I= 14 J=122 K= 5 |
| MR1  | 4.73 | 4.85 | 4.93 | 5.12 | 5.42 | 5.71 | 6.03 | 6.19 | 6.50 | I= 17 J= 82 K= 6 |
| MR2  | 4.77 | 4.91 | 5.03 | 5.26 | 5.55 | 5.79 | 6.01 | 6.11 | 6.22 | I= 21 J= 86 K= 6 |
| MR3  | 4.76 | 4.89 | 5.00 | 5.23 | 5.54 | 5.77 | 5.97 | 6.07 | 6.22 | I= 26 J= 94 K= 6 |
| MR4  | 4.90 | 5.04 | 5.15 | 5.41 | 5.70 | 6.11 | 6.38 | 6.56 | 6.82 | I= 26 J=105 K= 6 |
| MR5  | 3.17 | 3.78 | 4.08 | 4.77 | 6.61 | 7.36 | 7.81 | 7.93 | 8.11 | I= 23 J=123 K= 6 |
| MR6  | 2.64 | 2.65 | 2.66 | 2.70 | 2.81 | 3.02 | 3.26 | 3.39 | 3.49 | I= 20 J=118 K= 5 |
| LBR1 | 4.85 | 5.61 | 6.02 | 6.32 | 6.59 | 6.97 | 7.25 | 7.43 | 7.78 | I= 27 J=123 K= 6 |
| LBR2 | 5.16 | 5.43 | 5.56 | 5.73 | 5.95 | 6.19 | 6.41 | 6.56 | 6.76 | I= 39 J=122 K= 6 |
| LBR3 | 3.27 | 3.37 | 3.52 | 3.70 | 4.04 | 4.33 | 4.52 | 4.62 | 4.85 | I= 30 J= 86 K= 6 |
| BR1  | 3.52 | 3.64 | 3.72 | 3.90 | 4.28 | 4.54 | 4.72 | 4.77 | 4.88 | I= 32 J= 62 K= 6 |
| BR2  | 2.59 | 2.84 | 2.98 | 3.31 | 3.70 | 4.05 | 4.26 | 4.34 | 4.49 | I= 33 J= 65 K= 6 |
| BR3  | 2.99 | 3.08 | 3.14 | 3.30 | 3.57 | 4.02 | 4.22 | 4.31 | 4.41 | I= 30 J= 76 K= 6 |
| SCh1 | 2.33 | 2.65 | 2.75 | 2.93 | 3.30 | 4.05 | 4.35 | 4.45 | 4.62 | I= 10 J= 23 K= 6 |
| SCh2 | 3.87 | 3.97 | 4.09 | 4.22 | 4.39 | 4.55 | 4.66 | 4.74 | 4.85 | I= 7 J= 46 K= 6  |
| SR   | 6.15 | 6.25 | 6.46 | 6.84 | 7.06 | 7.34 | 7.81 | 7.91 | 8.01 | I= 13 J=128 K= 4 |
| StbR | 4.15 | 4.70 | 4.99 | 5.49 | 6.07 | 6.53 | 6.78 | 6.94 | 7.14 | I= 21 J=101 K= 6 |

\* The critical cell is the cell with lowest D.O. concentration within a Zone. Surface Layer K=1; Bottom Layer K=6.

**Table 7.5.3-12: Dissolved Oxygen Percentiles for Critical Cells (46 ft Project with Mitigation Plan 6a and DO Injection)**

| Zone | 1%   | 5%   | 10%  | 25%  | 50%  | 75%  | 90%  | 95%  | 99%  | Critical Cell*   |
|------|------|------|------|------|------|------|------|------|------|------------------|
| FR1  | 3.96 | 4.02 | 4.07 | 4.25 | 4.40 | 4.57 | 4.67 | 4.72 | 4.77 | I= 13 J= 39 K= 6 |
| FR2  | 3.81 | 3.90 | 3.97 | 4.21 | 4.37 | 4.54 | 4.77 | 4.86 | 4.91 | I= 15 J= 52 K= 6 |
| FR3  | 3.70 | 3.77 | 3.84 | 4.10 | 4.25 | 4.51 | 5.00 | 5.53 | 5.97 | I= 15 J= 59 K= 6 |
| FR4  | 3.71 | 3.76 | 3.86 | 4.12 | 4.28 | 4.55 | 5.03 | 5.49 | 6.05 | I= 15 J= 60 K= 6 |
| FR5  | 3.99 | 4.10 | 4.21 | 4.39 | 4.56 | 4.87 | 5.40 | 5.64 | 5.93 | I= 14 J= 72 K= 6 |
| FR6  | 4.05 | 4.11 | 4.25 | 4.41 | 4.55 | 4.86 | 5.43 | 5.77 | 5.96 | I= 14 J= 73 K= 6 |
| FR7  | 4.81 | 4.90 | 5.06 | 5.30 | 5.87 | 6.39 | 6.72 | 6.95 | 7.44 | I= 15 J= 86 K= 6 |
| FR8  | 4.74 | 4.88 | 5.09 | 5.40 | 6.37 | 6.84 | 7.08 | 7.20 | 7.35 | I= 14 J= 94 K= 5 |
| FR9  | 4.89 | 5.01 | 5.22 | 5.53 | 6.35 | 6.88 | 7.12 | 7.31 | 7.70 | I= 14 J= 99 K= 6 |
| FR10 | 6.20 | 6.44 | 6.57 | 6.90 | 7.12 | 7.39 | 7.83 | 7.93 | 8.00 | I= 13 J=120 K= 4 |
| FR11 | 2.71 | 2.71 | 2.72 | 2.74 | 2.78 | 2.89 | 3.03 | 3.11 | 3.18 | I= 14 J=122 K= 5 |
| MR1  | 4.72 | 4.85 | 4.93 | 5.12 | 5.45 | 5.72 | 6.00 | 6.14 | 6.52 | I= 17 J= 82 K= 6 |
| MR2  | 4.85 | 5.00 | 5.12 | 5.34 | 5.61 | 5.80 | 6.03 | 6.14 | 6.23 | I= 21 J= 86 K= 6 |
| MR3  | 4.86 | 4.98 | 5.07 | 5.32 | 5.60 | 5.83 | 5.98 | 6.11 | 6.22 | I= 26 J= 94 K= 6 |
| MR4  | 4.99 | 5.12 | 5.22 | 5.51 | 5.82 | 6.25 | 6.53 | 6.75 | 6.97 | I= 26 J=105 K= 6 |
| MR5  | 3.33 | 3.94 | 4.25 | 4.91 | 6.75 | 7.58 | 8.01 | 8.14 | 8.38 | I= 23 J=123 K= 6 |
| MR6  | 2.64 | 2.65 | 2.66 | 2.70 | 2.81 | 3.02 | 3.26 | 3.39 | 3.49 | I= 20 J=118 K= 5 |
| LBR1 | 5.04 | 5.71 | 6.14 | 6.46 | 6.74 | 7.14 | 7.42 | 7.61 | 7.94 | I= 27 J=123 K= 6 |
| LBR2 | 5.51 | 5.59 | 5.70 | 5.86 | 6.09 | 6.34 | 6.57 | 6.71 | 7.01 | I= 39 J=122 K= 6 |
| LBR3 | 3.34 | 3.47 | 3.62 | 3.80 | 4.14 | 4.47 | 4.62 | 4.78 | 4.97 | I= 30 J= 86 K= 6 |
| BR1  | 3.59 | 3.68 | 3.78 | 3.95 | 4.32 | 4.56 | 4.72 | 4.78 | 4.92 | I= 32 J= 62 K= 6 |
| BR2  | 2.80 | 2.91 | 3.05 | 3.36 | 3.76 | 4.08 | 4.29 | 4.36 | 4.51 | I= 33 J= 65 K= 6 |
| BR3  | 3.05 | 3.20 | 3.26 | 3.39 | 3.84 | 4.14 | 4.36 | 4.44 | 4.56 | I= 30 J= 75 K= 6 |
| SCh1 | 2.55 | 2.67 | 2.80 | 2.99 | 3.16 | 3.41 | 3.74 | 3.90 | 4.04 | I= 10 J= 24 K= 6 |
| SCh2 | 3.84 | 3.93 | 4.06 | 4.24 | 4.43 | 4.58 | 4.70 | 4.78 | 4.90 | I= 7 J= 45 K= 6  |
| SR   | 6.15 | 6.26 | 6.47 | 6.84 | 7.07 | 7.34 | 7.82 | 7.92 | 8.02 | I= 13 J=128 K= 4 |
| StbR | 4.18 | 4.74 | 5.04 | 5.55 | 6.12 | 6.57 | 6.82 | 6.93 | 7.10 | I= 21 J=101 K= 6 |

\* The critical cell is the cell with lowest D.O. concentration within a Zone. Surface Layer K= 1; Bottom Layer K= 6.



**Table 7.5.3-13: Dissolved Oxygen Percentiles for Critical Cells (47 ft Project with Mitigation Plan 6a and DO Injection)**

| Zone | 1%   | 5%   | 10%  | 25%  | 50%  | 75%  | 90%  | 95%  | 99%  | Critical Cell*   |
|------|------|------|------|------|------|------|------|------|------|------------------|
| FR1  | 3.99 | 4.05 | 4.10 | 4.27 | 4.39 | 4.56 | 4.68 | 4.72 | 4.81 | I= 13 J= 40 K= 6 |
| FR2  | 3.86 | 3.93 | 4.00 | 4.19 | 4.38 | 4.55 | 4.73 | 4.84 | 4.90 | I= 15 J= 52 K= 6 |
| FR3  | 3.74 | 3.82 | 3.89 | 4.14 | 4.29 | 4.59 | 5.01 | 5.64 | 5.97 | I= 15 J= 59 K= 6 |
| FR4  | 3.77 | 3.84 | 3.93 | 4.17 | 4.34 | 4.67 | 5.10 | 5.55 | 6.00 | I= 15 J= 60 K= 6 |
| FR5  | 4.14 | 4.39 | 4.52 | 4.68 | 5.03 | 5.39 | 5.66 | 5.96 | 6.18 | I= 13 J= 67 K= 5 |
| FR6  | 4.23 | 4.38 | 4.47 | 4.64 | 4.81 | 5.16 | 5.57 | 5.87 | 6.04 | I= 14 J= 73 K= 5 |
| FR7  | 4.88 | 4.97 | 5.12 | 5.37 | 5.91 | 6.41 | 6.78 | 7.09 | 7.87 | I= 15 J= 86 K= 6 |
| FR8  | 4.83 | 4.91 | 5.04 | 5.32 | 6.09 | 6.56 | 6.88 | 7.03 | 7.18 | I= 14 J= 94 K= 6 |
| FR9  | 4.97 | 5.07 | 5.24 | 5.53 | 6.28 | 6.86 | 7.12 | 7.24 | 7.35 | I= 14 J= 99 K= 6 |
| FR10 | 6.21 | 6.44 | 6.57 | 6.91 | 7.12 | 7.39 | 7.83 | 7.94 | 8.00 | I= 13 J=120 K= 4 |
| FR11 | 2.71 | 2.71 | 2.72 | 2.74 | 2.78 | 2.89 | 3.03 | 3.11 | 3.18 | I= 14 J=122 K= 5 |
| MR1  | 4.82 | 4.93 | 5.03 | 5.19 | 5.48 | 5.74 | 5.94 | 6.09 | 6.47 | I= 17 J= 82 K= 6 |
| MR2  | 4.86 | 4.98 | 5.10 | 5.26 | 5.47 | 5.72 | 5.95 | 6.06 | 6.27 | I= 21 J= 83 K= 6 |
| MR3  | 4.84 | 4.98 | 5.05 | 5.28 | 5.59 | 5.82 | 5.98 | 6.07 | 6.22 | I= 26 J= 94 K= 6 |
| MR4  | 4.99 | 5.11 | 5.23 | 5.53 | 5.82 | 6.26 | 6.54 | 6.72 | 6.99 | I= 26 J=105 K= 6 |
| MR5  | 3.34 | 3.94 | 4.27 | 4.92 | 6.75 | 7.58 | 8.02 | 8.14 | 8.38 | I= 23 J=123 K= 6 |
| MR6  | 2.64 | 2.65 | 2.66 | 2.70 | 2.81 | 3.02 | 3.26 | 3.39 | 3.49 | I= 20 J=118 K= 5 |
| LBR1 | 5.07 | 5.70 | 6.14 | 6.47 | 6.74 | 7.14 | 7.43 | 7.62 | 7.94 | I= 27 J=123 K= 6 |
| LBR2 | 5.53 | 5.60 | 5.73 | 5.89 | 6.11 | 6.36 | 6.61 | 6.80 | 7.12 | I= 39 J=122 K= 6 |
| LBR3 | 3.34 | 3.46 | 3.62 | 3.79 | 4.12 | 4.45 | 4.63 | 4.73 | 4.94 | I= 30 J= 86 K= 6 |
| BR1  | 3.69 | 3.78 | 3.86 | 4.04 | 4.38 | 4.61 | 4.77 | 4.82 | 4.94 | I= 32 J= 62 K= 6 |
| BR2  | 2.81 | 3.01 | 3.19 | 3.43 | 3.85 | 4.15 | 4.36 | 4.42 | 4.57 | I= 33 J= 65 K= 6 |
| BR3  | 3.12 | 3.20 | 3.26 | 3.43 | 3.72 | 4.15 | 4.32 | 4.47 | 4.58 | I= 30 J= 76 K= 6 |
| SCh1 | 2.39 | 2.66 | 2.80 | 2.97 | 3.21 | 3.99 | 4.33 | 4.44 | 4.60 | I= 10 J= 23 K= 6 |
| SCh2 | 3.84 | 3.93 | 4.07 | 4.26 | 4.43 | 4.57 | 4.69 | 4.74 | 4.87 | I= 7 J= 45 K= 6  |
| SR   | 6.15 | 6.26 | 6.47 | 6.84 | 7.07 | 7.34 | 7.82 | 7.92 | 8.02 | I= 13 J=128 K= 4 |
| StbR | 4.15 | 4.75 | 5.01 | 5.54 | 6.11 | 6.54 | 6.80 | 6.92 | 7.11 | I= 21 J=101 K= 6 |

\* The critical cell is the cell with lowest D.O. concentration within a Zone. Surface Layer K=1; Bottom Layer K=6.



**Table 7.5.3-14: Dissolved Oxygen Percentiles for Critical Cells (48 ft Project with Mitigation Plan 6a and DO Injection)**

| Zone | 1%   | 5%   | 10%  | 25%  | 50%  | 75%  | 90%  | 95%  | 99%  | Critical Cell*   |
|------|------|------|------|------|------|------|------|------|------|------------------|
| FR1  | 4.01 | 4.06 | 4.11 | 4.34 | 4.44 | 4.56 | 4.64 | 4.68 | 4.72 | I= 13 J= 37 K= 6 |
| FR2  | 3.84 | 3.93 | 3.99 | 4.20 | 4.40 | 4.56 | 4.77 | 4.84 | 4.90 | I= 15 J= 52 K= 6 |
| FR3  | 3.76 | 3.82 | 3.93 | 4.16 | 4.35 | 4.75 | 5.11 | 5.65 | 6.03 | I= 15 J= 59 K= 6 |
| FR4  | 3.80 | 3.86 | 4.00 | 4.22 | 4.42 | 4.85 | 5.26 | 5.65 | 6.05 | I= 15 J= 60 K= 6 |
| FR5  | 4.24 | 4.48 | 4.68 | 4.87 | 5.20 | 5.55 | 5.82 | 6.02 | 6.19 | I= 13 J= 67 K= 5 |
| FR6  | 4.31 | 4.43 | 4.64 | 4.78 | 5.03 | 5.34 | 5.69 | 5.91 | 6.09 | J= 14 J= 73 K= 5 |
| FR7  | 5.06 | 5.13 | 5.24 | 5.48 | 5.94 | 6.38 | 6.69 | 6.94 | 7.84 | I= 15 J= 86 K= 6 |
| FR8  | 4.97 | 5.06 | 5.18 | 5.43 | 6.03 | 6.49 | 6.82 | 6.93 | 7.10 | I= 14 J= 94 K= 6 |
| FR9  | 5.08 | 5.16 | 5.35 | 5.61 | 6.16 | 6.76 | 7.03 | 7.14 | 7.28 | I= 14 J= 99 K= 6 |
| FR10 | 6.17 | 6.37 | 6.52 | 6.84 | 7.07 | 7.33 | 7.78 | 7.85 | 7.97 | I= 13 J=119 K= 4 |
| FR11 | 2.71 | 2.71 | 2.72 | 2.74 | 2.78 | 2.89 | 3.03 | 3.11 | 3.18 | I= 14 J=122 K= 5 |
| MR1  | 4.89 | 5.06 | 5.15 | 5.32 | 5.52 | 5.76 | 5.94 | 6.02 | 6.18 | I= 21 J= 82 K= 6 |
| MR2  | 4.79 | 5.03 | 5.13 | 5.30 | 5.48 | 5.71 | 5.93 | 6.03 | 6.18 | I= 21 J= 83 K= 6 |
| MR3  | 4.74 | 4.92 | 4.98 | 5.23 | 5.52 | 5.76 | 5.91 | 6.01 | 6.20 | I= 26 J= 94 K= 6 |
| MR4  | 4.90 | 5.02 | 5.14 | 5.43 | 5.72 | 6.12 | 6.39 | 6.58 | 6.84 | I= 26 J=105 K= 6 |
| MR5  | 3.18 | 3.76 | 4.11 | 4.78 | 6.62 | 7.36 | 7.80 | 7.94 | 8.11 | I= 23 J=123 K= 6 |
| MR6  | 2.64 | 2.65 | 2.66 | 2.70 | 2.81 | 3.02 | 3.26 | 3.39 | 3.49 | I= 20 J=118 K= 5 |
| LBR1 | 4.94 | 5.53 | 6.00 | 6.33 | 6.60 | 7.00 | 7.27 | 7.44 | 7.80 | I= 27 J=123 K= 6 |
| LBR2 | 5.37 | 5.44 | 5.59 | 5.75 | 5.97 | 6.23 | 6.45 | 6.57 | 6.74 | I= 39 J=122 K= 6 |
| LBR3 | 3.24 | 3.34 | 3.49 | 3.68 | 4.01 | 4.32 | 4.53 | 4.61 | 4.80 | I= 30 J= 86 K= 6 |
| BR1  | 3.74 | 3.84 | 3.91 | 4.08 | 4.42 | 4.64 | 4.80 | 4.86 | 4.98 | I= 32 J= 62 K= 6 |
| BR2  | 2.84 | 3.05 | 3.20 | 3.49 | 3.89 | 4.20 | 4.40 | 4.46 | 4.59 | I= 33 J= 65 K= 6 |
| BR3  | 3.05 | 3.14 | 3.20 | 3.38 | 3.67 | 4.16 | 4.34 | 4.48 | 4.60 | I= 30 J= 76 K= 6 |
| SCh1 | 2.39 | 2.66 | 2.82 | 3.01 | 3.28 | 4.06 | 4.31 | 4.45 | 4.58 | I= 10 J= 23 K= 6 |
| SCh2 | 3.84 | 3.94 | 4.07 | 4.24 | 4.44 | 4.59 | 4.70 | 4.76 | 4.89 | I= 7 J= 45 K= 6  |
| SR   | 6.14 | 6.25 | 6.46 | 6.84 | 7.07 | 7.34 | 7.81 | 7.91 | 8.01 | I= 13 J=128 K= 4 |
| StbR | 4.04 | 4.66 | 4.97 | 5.47 | 6.05 | 6.45 | 6.71 | 6.83 | 7.02 | I= 21 J=101 K= 6 |

\* The critical cell is the cell with lowest D.O. concentration within a Zone. Surface Layer K=1; Bottom Layer K=6.

### 7.5.4 Proposed Mitigation Features and Fishery Habitat

The proposed mitigation features were developed based on salinity impacts to freshwater wetlands, partially due to the tidal freshwater marshes being identified by the USFWS as the single most critical natural resource in the harbor. However, the selected mitigation plans were also evaluated to determine impacts to fishery habitat, chloride concentrations, and hurricane surges.

Impacts to fishery habitat were evaluated with the proposed mitigation plans. Results are documented in several reports, all of which are included in the Engineering Investigations Supplemental Materials. A list of these reports is shown below:

- *Evaluation of Fishery Habitat Impacts with Proposed Mitigation Plan, January 2010*
- *Evaluation of Adult Shortnose Sturgeon (Summer) Habitat Impacts with Proposed Mitigation Plan, March 11, 2011*
- *Evaluation of Adult Shortnose Sturgeon (Winter) Habitat Impacts with Proposed Mitigation Plan, March 9, 2011*
- *Evaluation of Juvenile Shortnose Sturgeon (Winter) Habitat Impacts with Proposed Mitigation Plan, March 9, 2011*

Resulting fishery habitat impacts by acreage and percentage lost or gained as reported in these documents are shown in **Tables 7.5.4-1** through **7.5.4-4**.

The mitigation features were designed to reduce salinity intrusion in the estuary along with mitigating for impacts to water quality, specifically D.O. The features do have some benefits to fish habitat; however, the mitigation plans do not fully mitigate for impacts to fish within the estuary. Several other strategies and features have been evaluated with the model to reduce impacts to fish. However, many have not been successful. Details of the previously proposed feature intended to benefit Juvenile Shortnose sturgeon (SNS) habitat which involves construction of a sill on lower Middle River can be found in the report titled *Sensitivity Analysis of Proposed Sill on Middle River* dated September 2009 which is included in the Engineering Investigations Supplemental Materials. Results of the Middle River sill analysis do show some promise in reducing the expected salinity increases with harbor deepening in a deep hole on Middle River where Juvenile SNS have been observed during cool months of the year; however, the benefits to fish habitat from the sill are shown to be marginal.

**Table 7.5.4-1: Fishery Impacts – American Shad (Deepening & Mitigation)**

|             | May20%flows     |                 | May50%flows      |                 | May80%flows |                 |
|-------------|-----------------|-----------------|------------------|-----------------|-------------|-----------------|
|             | IMPACTS (%)     | IMPACTS (acres) | IMPACTS (%)      | IMPACTS (acres) | IMPACTS (%) | IMPACTS (acres) |
| 44 ft depth | -0.2%           | -12             | -0.2%            | -12             | -0.2%       | -12             |
| 45 ft depth | -0.2%           | -11             | -0.2%            | -11             | -0.2%       | -11             |
| 46 ft depth | -0.2%           | -11             | -0.2%            | -11             | -0.2%       | -11             |
| 47 ft depth | -0.2%           | -11             | -0.2%            | -11             | -0.2%       | -11             |
| 48 ft depth | -0.2%           | -11             | -0.2%            | -11             | -0.2%       | -11             |
|             | January50%flows |                 | August Avg flows |                 |             |                 |
|             | IMPACTS (%)     | IMPACTS (acres) | IMPACTS (%)      | IMPACTS (acres) |             |                 |
| 44 ft depth | -0.2%           | -9              | -0.3%            | -16             |             |                 |
| 45 ft depth | -0.2%           | -9              | -0.3%            | -15             |             |                 |
| 46 ft depth | -0.2%           | -9              | -0.2%            | -11             |             |                 |
| 47 ft depth | -0.2%           | -9              | -0.2%            | -11             |             |                 |
| 48 ft depth | -0.2%           | -9              | -0.2%            | -11             |             |                 |

**Table 7.5.4-2a: Fishery Impacts – Striped Bass Eggs (Deepening & Mitigation)**

|             | April20%flows |                 | April50%flows |                 | April80%flows |                 |
|-------------|---------------|-----------------|---------------|-----------------|---------------|-----------------|
|             | IMPACTS (%)   | IMPACTS (acres) | IMPACTS (%)   | IMPACTS (acres) | IMPACTS (%)   | IMPACTS (acres) |
| 44 ft depth | -22.3%        | -215            | -9.4%         | -157            | 7.6%          | 171             |
| 45 ft depth | -17.6%        | -169            | 5.2%          | 87              | 8.0%          | 181             |
| 46 ft depth | -7.8%         | -75             | 0.0%          | 0               | 6.9%          | 155             |
| 47 ft depth | -12.1%        | -117            | -11.1%        | -186            | 5.0%          | 113             |
| 48 ft depth | -4.6%         | -44             | -10.8%        | -181            | 3.4%          | 76              |

**Table 7.5.4-2b: Fishery Impacts – Striped Bass Larvae (Deepening & Mitigation)**

|             | May20%flows |                 | May50%flows |                 | May80%flows |                 |
|-------------|-------------|-----------------|-------------|-----------------|-------------|-----------------|
|             | IMPACTS (%) | IMPACTS (acres) | IMPACTS (%) | IMPACTS (acres) | IMPACTS (%) | IMPACTS (acres) |
| 44 ft depth | 174.6%      | 348             | -5.6%       | -32             | -13.7%      | -136            |
| 45 ft depth | 187.4%      | 374             | 1.7%        | 9               | 7.6%        | 75              |
| 46 ft depth | 191.4%      | 382             | 5.6%        | 32              | 10.1%       | 100             |
| 47 ft depth | 178.7%      | 356             | -5.0%       | -28             | 26.4%       | 262             |
| 48 ft depth | 154.6%      | 308             | -3.5%       | -20             | 30.0%       | 298             |

**Table 7.5.4-2c: Fishery Impacts – Striped Bass Spawning (Deepening & Mitigation)**

|             | April20%flows |                 | April50%flows |                 | April80%flows |                 |
|-------------|---------------|-----------------|---------------|-----------------|---------------|-----------------|
|             | IMPACTS (%)   | IMPACTS (acres) | IMPACTS (%)   | IMPACTS (acres) | IMPACTS (%)   | IMPACTS (acres) |
| 44 ft depth | -15.2%        | -97             | -2.9%         | -30             | -2.9%         | -53             |
| 45 ft depth | -13.9%        | -89             | -9.2%         | -96             | -8.5%         | -156            |
| 46 ft depth | -18.7%        | -120            | -10.0%        | -104            | -10.8%        | -199            |
| 47 ft depth | -21.1%        | -135            | -13.5%        | -140            | -12.7%        | -234            |
| 48 ft depth | -23.9%        | -153            | -16.1%        | -167            | -13.2%        | -242            |

**Table 7.5.4-3: Fishery Impacts – Shortnose sturgeon (Deepening & Mitigation)**

|             | JUVENILES   |                 | ADULTS      |                 |             |                 |
|-------------|-------------|-----------------|-------------|-----------------|-------------|-----------------|
|             | January     |                 | January     |                 | August *    |                 |
|             | IMPACTS (%) | IMPACTS (acres) | IMPACTS (%) | IMPACTS (acres) | IMPACTS (%) | IMPACTS (acres) |
| 44 ft depth | -6.7%       | -220            | -3.9%       | -153            | 19.0%       | 260             |
| 45 ft depth | -7.0%       | -231            | -4.6%       | -179            | 9.8%        | 134             |
| 46 ft depth | -7.3%       | -238            | -6.2%       | -240            | 7.3%        | 100             |
| 47 ft depth | -7.6%       | -251            | -6.9%       | -266            | 6.5%        | 89              |
| 48 ft depth | -11.5%      | -376            | -8.4%       | -326            | 2.8%        | 39              |

\*Habitat gains shown during August for Adult SNS are largely due to implementation of the D.O. injection system.

**Table 7.5.4-4: Fishery Impacts – Southern Flounder (Deepening & Mitigation)**

|             | August Avg flows |                 |
|-------------|------------------|-----------------|
|             | IMPACTS (%)      | IMPACTS (acres) |
| 44 ft depth | 74.1%            | 1387            |
| 45 ft depth | 54.2%            | 1014            |
| 46 ft depth | 57.3%            | 1072            |
| 47 ft depth | 57.3%            | 1072            |
| 48 ft depth | 52.9%            | 989             |

### 7.5.5 Proposed Mitigation Features and Hurricane Surge

Hurricane Surge analysis was also completed with the proposed mitigation feature design. The model has the same limitations noted in the impact analysis but is useful for comparative purposes. The results of the analysis show that there is little impact expected on hurricane surge at Fort Jackson or further upstream at the I-95 Bridge (the two areas identified for result measurements). The largest increase predicted by the model is 0.8 ft at the I-95 Bridge. Details of the hurricane surge analysis can be found in the report titled, *Evaluation of Hurricane Surge Impacts with Proposed Mitigation Plan*, which is included in the Engineering Investigations Supplemental Materials.

### 7.5.6 Proposed Mitigation Features and 1 Percent Annual Chance Storm (100-Year)

The 1% annual chance storm, i.e. 100-year flood event, in the vicinity of SHEP is a hurricane surge event. According to the most recent FEMA Flood Insurance Study (FIS) which was published September 26, 2008, base flood elevations for the Savannah River in Chatham County range from 12 ft NAVD (16 ft MLLW) and above along the river through the SHEP to the ocean front at Tybee Island. Based on the FEMA designated base flood elevations throughout the Savannah River estuary, all of the flow-altering mitigation features would be significantly submerged during the 1% annual chance storm and would therefore be expected to have a minimal effect on base flood elevations.

Furthermore, the FEMA FIS models used in the coastal zone do not have the detail necessary to evaluate channel deepening and mitigation features. The coastal zone models concentrate on simulating overland flow and wave run-up associated with very large wind-driven storm events. The SHEP hydrodynamic and water quality models do not fall into the same category and the resulting output is not appropriate for comparison to the published FEMA datasets.

## 7.6 MODEL SENSITIVITY WITH PROPOSED NAVIGATION CHANNEL FEATURES (MEETING AREAS & BEND WIDENERS)

Meeting areas and bend widener features were not originally included in the model grid when it was developed and enhanced for impact evaluation and mitigation feature development. An evaluation of the possible impacts due to incorporation of these features in the SHEP to freshwater wetlands/marshes and water quality within the estuary was performed as sensitivity analysis. The results are reported below.

### 7.6.1 Meeting Areas

Meeting areas proposed for the final channel design were not originally incorporated into the model grid because they had not yet been developed. However, after the meeting areas were proposed, a hydrodynamic modeling sensitivity analysis was performed with the final mitigation plan and proposed meeting areas to determine the impacts to freshwater marshes/wetlands and to water quality (dissolved oxygen, D.O.) within the Savannah River estuary. Details of this analysis can be found in the report titled *Sensitivity Analysis of Proposed Navigation Meeting Areas*, which is included in the Engineering Investigations Supplemental Materials. **Table 7.6.1-1** and **Figure 7.6.1-1** show the locations of the two meeting areas (Long Island and Oglethorpe) included in the final channel design along with their stationing, length, and width.

**Table 7.6.1-1: Meeting Area Dimensions and Locations**

| Meeting Area | Length (ft) | Width* (ft) | Stationing       |
|--------------|-------------|-------------|------------------|
| Long Island  | 8,000       | 100         | 14+000 to 22+000 |
| Oglethorpe   | 4,000       | 100         | 54+800 to 58+800 |

*\* Width is in addition to the width of the navigation channel at the toe of the channel sideslope.*

**Figure 7.6.1-1: Meeting Area Locations**



#### 7.6.1.1 Hydrodynamic & Water Quality Model Input

The two meeting areas shown in **Figure 7.6.1-1** were incorporated into the EFDC and WASP model grids by adjusting the widths of several grid cells along the navigation channel. The cells that have been widened are representative channel cells; cells that have been reduced in width represent adjacent bank and sideslope transition cells. See **Table 7.6.1.1-1**.

**Table 7.6.1.1-1: Meeting Area Model Parameters**

| Meeting Area | EFDC Model Grid Adjustments*                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Long Island  | widen cell <b>14_28</b> by 100 feet (30.5 m) -- from 153.75m to 184.25m<br>reduce width of cell <b>13_28</b> by 100 feet (30.5m) -- from 265.81m to 235.31m<br>widen cell <b>14_27</b> by 100 feet (30.5 m) -- from 154.4m to 184.9m<br>reduce width of cell <b>13_27</b> by 100 feet (30.5m) -- from 245.15m to 214.65m<br>widen cell <b>14_26</b> by 25 feet (7.62m) -- from 175.28m to 182.9m<br>reduce width of cell <b>13_26</b> by 25 feet (7.62m) -- from 208.99m to 201.37m |
| Oglethorpe   | widen cell <b>14_50</b> by 85 feet (25.9 m) -- from 163.43m to 189.33m<br>reduce width of cell <b>15_50</b> by 85 feet (25.9 m) -- from 143.61m to 117.71m<br>widen cell <b>14_49</b> by 100 ft (30.5 m) -- from 150.85m to 181.35m<br>reduce width of cell <b>15_49</b> by 100 ft (30.5 m) -- from 94.36m to 63.86m<br>widen cell <b>14_48</b> by 100 ft (30.5 m) -- from 165.93m to 196.43m<br>reduce width of cell <b>15_48</b> by 100 ft (30.5 m) -- from 88.2m to 57.7m        |

\*Adjustments made by changing the *DX* value in the *daly.inp* file.

Several model run scenarios were analyzed to determine if there are any additional impacts as a result of the two proposed meeting areas. Two scenarios for freshwater marsh/wetland impacts were evaluated, 1) an average freshwater flow year, considered the “Basic Evaluation”, and 2) a low freshwater flow year, considered “Sensitivity Analysis #1”. See **Table 7.6.1.1-2**. For more information on how these run scenarios were developed see the report titled *Evaluation of Marsh/Wetland Impacts with Proposed Mitigation Plan*, which is included in the Engineering Investigations Supplemental Materials.

**Table 7.6.1.1-2: Model Input Conditions for Freshwater Marsh/Wetland Impacts**

| Run Scenario            | River Flow      | Evaluation Period     | Parameters Evaluated      |
|-------------------------|-----------------|-----------------------|---------------------------|
| Basic Evaluation        | Average/Typical | 1-March to 1-November | Surface & Bottom Salinity |
| Sensitivity Analysis #1 | Low Flow/Dry    | 1-March to 1-November | Surface Salinity Only     |

In addition to the analysis performed for marsh/wetland impacts, an analysis was also done to determine water quality (i.e., D.O.) impacts. One time-period scenario was analyzed for this purpose. The run period is August of 1997, an average flow summer-month period.

All run scenarios incorporate the 48 ft project depth (considered a “worst-case” scenario for the sensitivity analysis) along with the proposed mitigation plan for that depth (Plan 6a and D.O. injection).



### 7.6.1.2 Findings

Impacts to tidal fluctuations within the estuary due to inclusion of the meeting areas were examined at several grid cell locations on Back and Middle Rivers. Details of tidal variability by water depth were evaluated. Comparisons are made between the 48 ft depth alternative with Mitigation Plan 6a in place with and without the meeting areas modeled. None of the locations along Middle and Back River show an impact to tidal depth or timing as a result of inclusion of the meeting areas within the model geometry.

Impacts to the salinity regime within the estuary due to inclusion of the meeting areas in the model grid geometry were also examined. Again, comparisons are made between the 48 ft depth alternative with Mitigation Plan 6a in place with and without the meeting areas modeled. The changes in surface and bottom salinity predictions were evaluated under conditions experienced within the estuary on an average basis (the Basic Evaluation run period). The maximum change in the surface salinity prediction for the Basic Evaluation is 0.14 ppt. This change occurs just upstream of the tidegate on Back River and causes an increase in the salinity prediction from 5.88 ppt to 6.02 ppt. Surface salinity changes under the Basic Evaluation conditions extend up to New Cut on Back River. However, the increases in prediction values in that area are minor, 0.01 ppt. Additionally, the change in salinity regime causes a decrease in predicted surface salinity values on Front River up to 0.44 ppt.

Comparatively, the maximum change in the bottom salinity prediction during Basic Evaluation conditions is 0.33 ppt and occurs on Front River just upstream of Elba Island. The addition of the meeting areas within the model cause the bottom salinity to increase from 19.25 ppt to 19.58 ppt. Changes in bottom salinity for the Basic Evaluation, although very small (less than 0.1 ppt), are seen as far upstream as New Cut on Back River. However, this change or shift in the salinity regime causes a decrease in predicted bottom salinity values on Front River up to almost 0.5 ppt.

Surface salinity changes under the Sensitivity Analysis #1 (low flow/drought conditions). Increases are seen throughout Front, Middle and Back Rivers. However, the increases are minor (under 0.17 ppt).

Impacts to D.O. within the estuary due to inclusion of the meeting areas in the model grid were also evaluated and results were analyzed for the changes in D.O. percentiles for critical cells and zones. A critical cell is the cell with the lowest D.O. concentrations during the simulation. The critical cell is found within each zone. A zone is an assemblage of cells that is limited by specified horizontal and vertical boundaries. The maximum decrease in the critical cells for D.O. as a result of modification to the model grid occurs on Back River, near New Cut. The change is 0.26 mg/L, which is a 7% decrease in the predicted D.O. value. Conversely, there are some increases in D.O. as a result of the model grid modification as well, which occur on Front River. The change is 1.47 mg/L, which is a 16.2% increase. The maximum decrease in the zones for D.O. as a result of modification to the model grid occurs on Front River at the 95<sup>th</sup> percentile. The relative difference for this change in prediction is 1.2%. Comparatively, the maximum increase in D.O. as a result of modification to the grid is 0.13 mg/L for the 1<sup>st</sup> percentile and occurs on Back River and has a relative difference of 3%.

For both critical cell and zone comparisons the 50<sup>th</sup> percentile differences are very minor with D.O. changes less than 0.1 mg/L.



In summary, the changes due to model grid modification with addition of the meeting area geometries are minor. The impacts to tidal fluctuations and the salinity regime as shown by the model results are minor. The largest changes in salinity occur on the bottom of the river and are not expected to pose an impact to adjacent wetlands.

The largest impacts to D.O. as a result of the model grid occur at the extreme percentiles, 1<sup>st</sup> and 95<sup>th</sup> while the 50<sup>th</sup> percentile salinities changes are very minor.

For completeness, the meeting areas could be incorporated into the project conditions model grid. However, as shown by this sensitivity analysis, the changes are likely to have little to no impact on the previous estimates to freshwater marsh/wetland or water quality impacts and therefore no bearing on the mitigation plan or project cost estimates.

## 7.6.2 Bend Wideners

Despite the fact that the model grid was refined from the coarse grid originally developed by ATM, it doesn't have the precision scale required to evaluate bend wideners. The wideners were not included in the model grid during evaluation of impacts or during mitigation feature development, however, it is not expected that they would have appreciable impacts to salinity and D.O. regimes in the estuary.

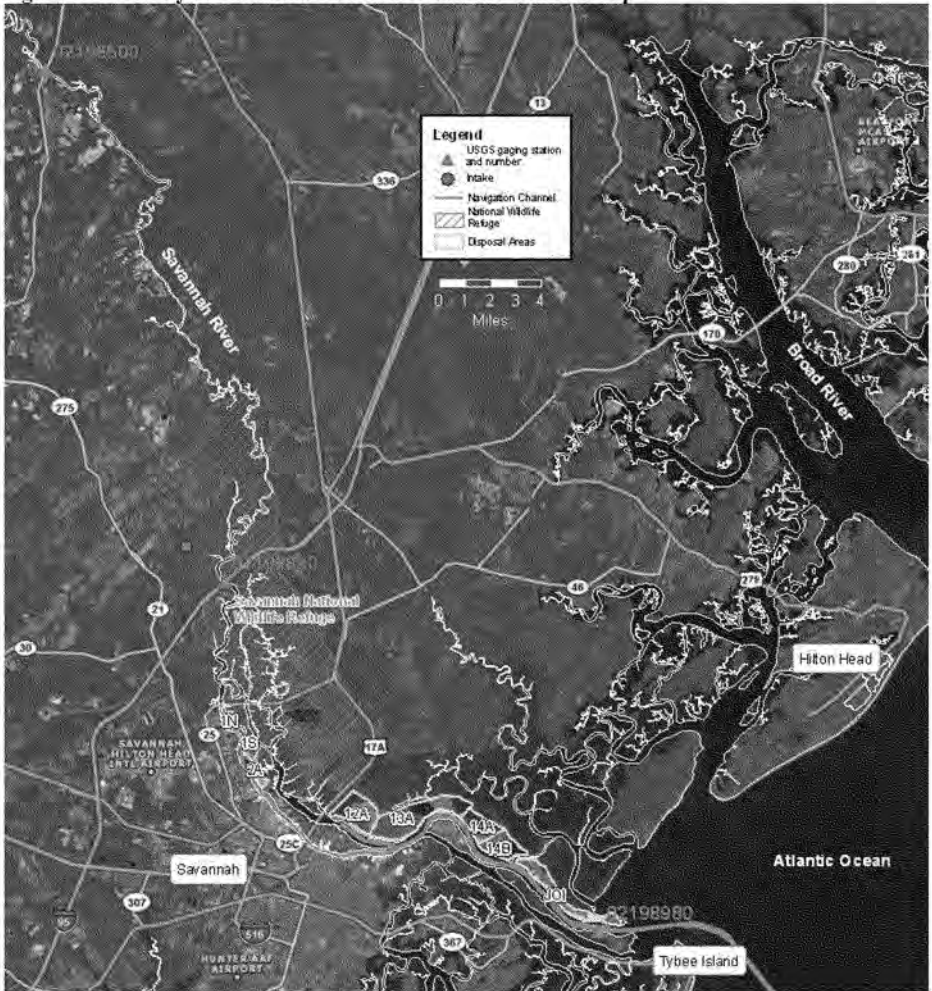
## 7.7 CHLORIDE MODELING AND ANALYSIS

### 7.7.1 Background

The City of Savannah operates a municipal and industrial water supply intake located on Abercorn Creek approximately two river miles from the confluence with the Savannah River in Effingham County, GA (See **Figure 7.7.1-1**). The water supply intake is approximately 11 river miles upstream of the proposed Savannah Harbor Expansion Project's deepening upstream limits and approximately 31 miles from the Atlantic Ocean. From the intake, raw water is piped 7.25 miles to a treatment facility in Port Wentworth, GA. Plant capacity is 62.5 million gallons per day (MGD); however, current withdrawal rates are around 30 MGD. Water supply from this source is utilized primarily by industrial users for specific plant processes; however, it also supplies residences in west Savannah, Pooler, and south Effingham County. In addition to this surface water supply, the City of Savannah operates a number of groundwater intakes at other locations and is under directive from the State of Georgia to decrease groundwater usage, which may increase demand for surface water from the Abercorn Creek intake.

Based on EFDC hydrodynamic modeling, the proposed deepening of Savannah Harbor will increase salinity and chloride concentrations in the upper reaches of the Savannah River Estuary, including Abercorn Creek. The EPA drinking water standard for chlorides has been established at 250 milligrams per liter (mg/l) as a Secondary Maximum Contaminant Level. This level is specified as a threshold of taste and odor detection and not as a health hazard. Distribution pipeline corrosion, including lead and copper in residential plumbing, and certain industrial processes are sensitive to chloride concentrations much lower than the drinking water standard.

Figure 7.7.1-1: City of Savannah Raw Water Intake Location Map

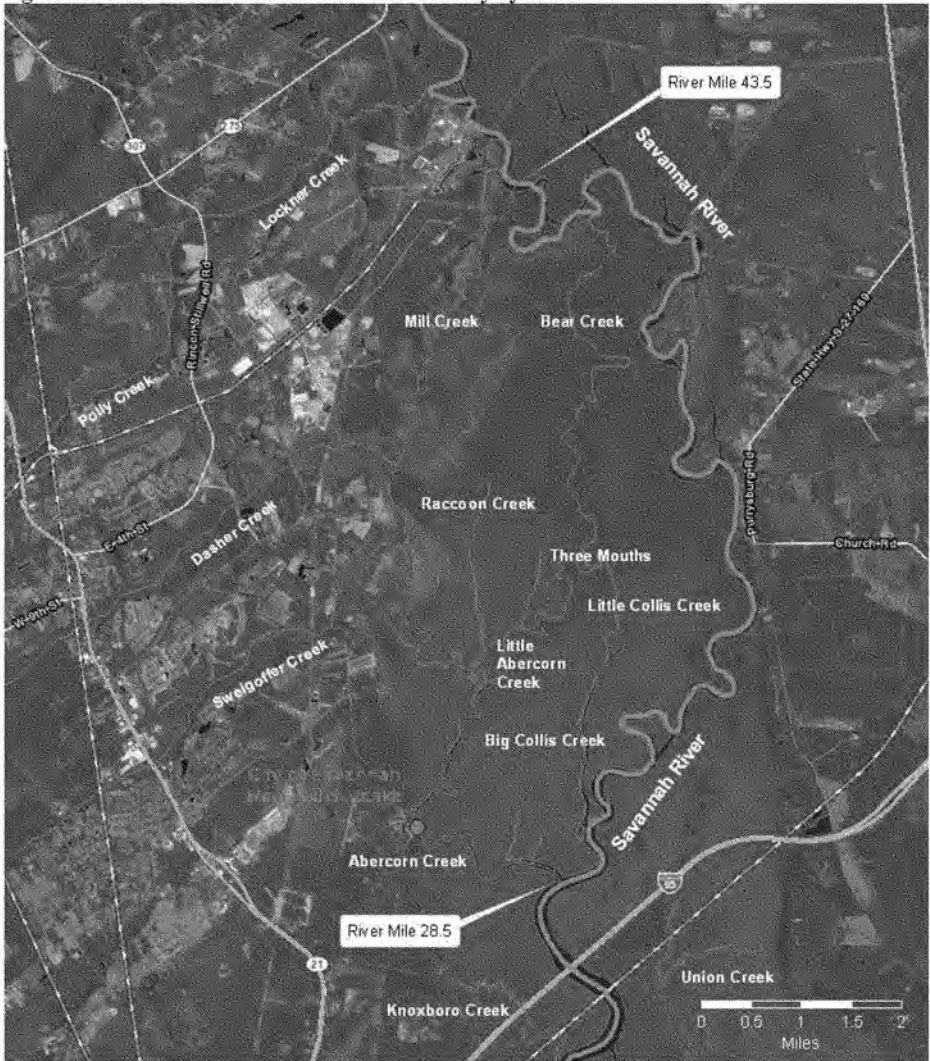


### 7.7.2 Location

Abercorn Creek is a tributary to the Savannah River located in the Coastal Plain of Georgia (See **Figure 7.7.2-1**). The creek is part of a braided river system in that it receives inflow from Bear and Mill Creeks, which branch off from the Savannah River as distributary streams about 10 miles upriver. The confluence of Abercorn Creek with the Savannah River is located approximately one mile upstream from the I-95 Bridge, at river mile 28.5.

Abercorn Creek is part of the tidal freshwater system with semi-diurnal tides. Currently, salinity concentrations on Abercorn Creek are less than 0.5 parts per thousand (ppt). Salinity intrudes into the Savannah River Estuary from the ocean, and the location of the saltwater-freshwater interface is a constantly changing balance between upstream river flows and downstream tidal conditions.

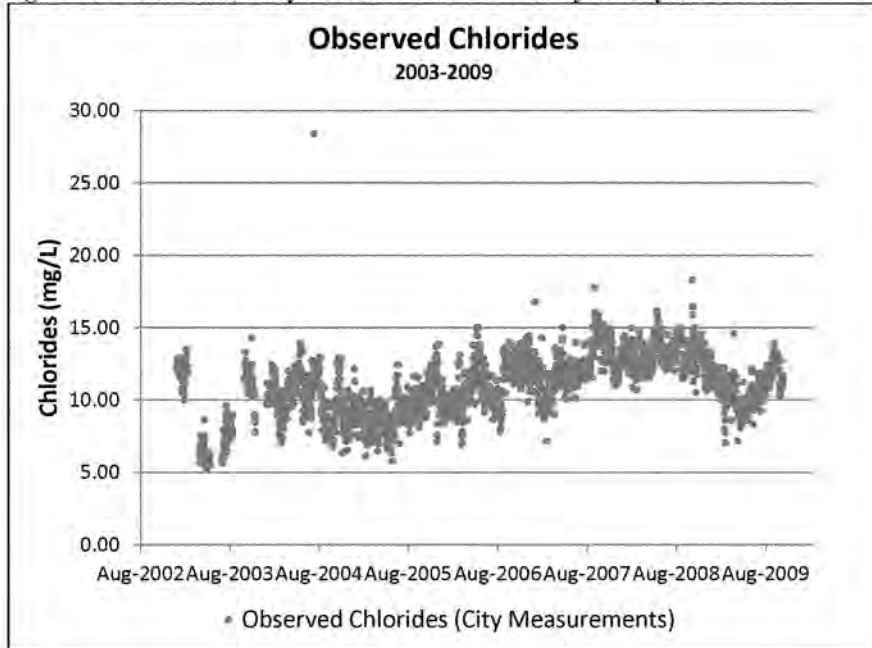
Figure 7.7.2-1: Lower Savannah River Distributary System



### 7.7.3 Existing Chloride Regime

Based on data collected by the City of Savannah, the level of chlorides at the water intake on Abercorn Creek has historically averaged 10 to 12 mg/l. This average is based on lab analysis by the City of Savannah on a daily composite sample of the raw water prior to treatment (See **Figure 7.7.3-1**) for the period January 2003 through 2009. Prior to 2003, the lab analysis was performed on a 7 am daily grab sample. The maximum chloride value for the measured data (28.4), as shown in **Figure 7.7.4-1**, is considered suspect because there were no preceding or following high values nor accompanying low flow and spring tide. Therefore, a maximum observed value of 18.3 mg/l was used in the statistical analysis.

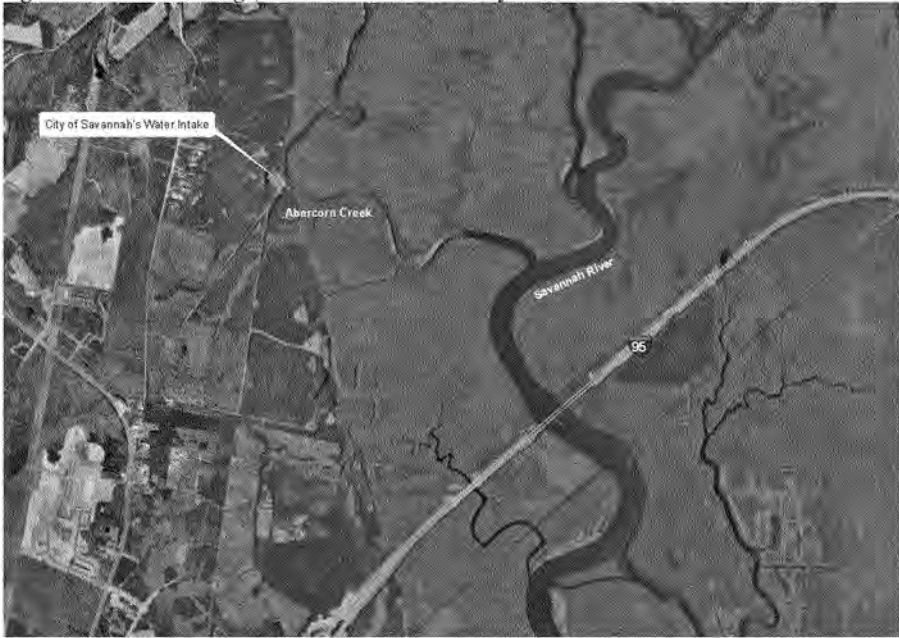
**Figure 7.7.3-1: Observed Daily Chloride Values Collected By the City of Savannah**



The salinity dynamics at the City's intake are significantly different from the dynamics at the I-95 Bridge, which is located approximately three miles downstream and regularly monitored for specific conductance by USGS gage 02198840. Salinity in the field is measured by specific conductance because it is much easier to measure in-situ and instantaneously. Salinity is not directly convertible to chlorides. In addition to salinity, there are other substances in water that contribute to chlorides and a temperature dependent relationship between conductivity and salinity. Normally, with brackish water, the non-salinity contribution to chlorides is so small that it is neglected; however, at Abercorn Creek which has very low chloride values, the non-salinity contribution to chlorides becomes an important consideration.

The spatial relationship of the Savannah River, the I-95 Bridge, and Abercorn Creek can be seen in **Figure 7.7.3-2**. The sharp salinity intrusions experienced at I-95 do not occur at the water intake but are dampened before reaching it. The specific conductance (field measurement for computing salinity) at I-95 shows sharp increases when streamflow measured at Clyo, GA (RM 61) decreases below 6,000 cubic feet per second ( $\text{ft}^3/\text{s}$ ) and a new moon occurs (28-day cyclical spring high tide).

**Figure 7.7.3-2: I-95 Bridge, Abercorn Creek and City of Savannah Water Intake Location**



### 7.7.3.1 Low Flow Effect on Chloride Regime

Field observations at I-95 show that upriver salinity intrusion occurs only at river flows less than 6,000 cfs. Flows greater than 6,000 cfs keep the higher saline waters lower in the estuary and do not allow them to move that far upstream.

**Table 7.7.3.1-1** depicts a duration analysis of flow data at the USGS Savannah River gage near Clyo, GA. The Clyo gage is located on the Savannah River at river mile 61 which is 32.5 miles above the confluence with Abercorn Creek. There are four analytical periods shown. The period 1929 – 2010 includes the entire period of record. The years 1954 – 2010 include the period of flow regulation by Thurmond Dam. The years 1987 – 2010 include the period during which the releases from Hartwell, Russell, and Thurmond reservoirs were operated using a drought plan designed to minimize impacts to all project purposes. The most recent years, 2001 – 2010, were low flow years.

**Table 7.7.3.1-1: Streamflow Frequency Analysis, Savannah River at Clio, GA**

|                        | Gage<br>Period-of-<br>Record | Flow<br>Regulated<br>by Corps Dams | Dam Releases<br>Governed by<br>Drought Plan | Low Flow<br>Period |
|------------------------|------------------------------|------------------------------------|---------------------------------------------|--------------------|
| Condition              | 1929-2010                    | 1953-2010                          | 1987-2010                                   | 2001-2010          |
| Streamflow <4,000 cfs  | 1%                           | 0%                                 | 0%                                          | 0%                 |
| Streamflow <5,000 cfs  | 6%                           | 3%                                 | 8%                                          | 15%                |
| Streamflow <6,000 cfs  | 17%                          | 14%                                | 26%                                         | 42%                |
| Streamflow <8,000 cfs  | 43%                          | 43%                                | 53%                                         | 67%                |
| Streamflow <11,000 cfs | 67%                          | 68%                                | 72%                                         | 80%                |
| Average Flow           | 11,460 cfs                   | 11,350 cfs                         | 10,520 cfs                                  | 8,740 cfs          |

The flow records differ among these three periods as a result of reservoir regulation and implementation of drought plan rules. Both affect low flows in the Savannah River. Flows during the period 1987 – 2010 were marked by recurrent droughts and an absence of significant flood events. The time period from 2001 – 2010 includes 2 prolonged extreme droughts, including the drought of record. Flows below 6,000 cfs were experienced 26% of the time during 1987 – 2010, while flows below 5,000 cfs were experienced 8% of the time. During the extremely dry 2001-2010 period, those percentages increased to 42% and 15%, respectively. These percentages are considered to be much higher than would be expected for the long term average. From this data, it is reasonable to conclude that the number of low flow occurrences (less than 6,000 cfs) was approximately doubled during 2001-2010, when compared to what would normally be expected.

The average flow for the period 1987-2010 is 8% below the long-term average and 24% below the long-term average for the 2001-2010 period. If the average annual flows from 1929 to 2010 are sorted from lowest to highest, the seven lowest years all occurred between 1987 and 2010; the four lowest occurred between 2001 and 2010. The drought-of-record for the basin was experienced during the period March 2007 to November 2009.

The first half of the twentieth century was marked by frequent disastrous floods in the basin, while the latter half of the century and the first decade of the 21<sup>st</sup> century experienced a marked absence of floods and numerous droughts. After converting all flood events to unregulated flow, to account for the impact of the Corps' three large multi-purpose storage projects upstream, 11 of the 12 largest flood events of the twentieth century occurred prior to 1950. These historic flood events illustrate the climatic variability and show that we are presently in an unusually dry period.



#### 7.7.4 Early Modeling Methodology & Impact Predictions

As part of the Savannah Harbor Expansion Project, Savannah District conducted a study to evaluate impacts to the City of Savannah's raw water intake on Abercorn Creek. An impact prediction tool was developed. The details of the development are outlined in the report titled *Savannah Harbor Expansion Project- Chloride Data Analysis and Model Development* dated November 15, 2006 which is included in the Engineering Investigations Supplemental Materials.

The objectives of this study were to:

Provide a statistical correlation between chloride levels at the City's intake, chloride levels at a nearby downstream station, and upstream flows.

Determine the likelihood of increased chloride levels at the City's intake.

Identify potential point and non-point sources of chlorides within the watershed.

Develop a chloride model to predict changes in concentrations at the City's intake.

Development of a statistical correlation was largely based on chloride data collected and analyzed by the City over the period 1988 to 2004. This is an extensive dataset with numerous chloride data points between 5 and 20 mg/l. The statistical correlation (equation) was developed to represent the data points. The correlation has a high level of accuracy predicting within the bounds of the data collected; however, for chlorides predicted outside of this range, the equation is less representative and has a greater margin of uncertainty.

Projection of chloride impacts due to harbor deepening and wetland mitigation using this method are documented in two reports *Chloride Impact Evaluation Impacts of Harbor Deepening Only* dated February 2007 and *Savannah Harbor Expansion Project Evaluation of Chloride Impacts with Proposed Mitigation Plan* dated December 2007, which are both included in the Engineering Investigations Supplemental Materials.

Study findings projected only negligible changes to the chloride concentrations resulting from harbor deepening. The projected impacts were less than 1 mg/l and occurred only during low river flows (less than 6,000 cfs measured at Clyo, GA).

During the review process, concerns were expressed by the independent technical reviewer (USGS) and the City of Savannah about the methodology used to identify potential project impacts and the uncertainties due to lack of chloride data. The Corps reviewed the comments and confirmed that the statistical equation used to predict project impacts was the best that could be developed with the available data. The impact analysis concluded that the impacts to chlorides levels on Abercorn Creek from a harbor deepening would not be significant. That conclusion was reported in the November 2010 Draft GRR and EIS documents.

To address the concerns about the technical reliability of the impact prediction tool, the District and GPA began an intensive campaign to collect additional chloride data. The additional data would be used to improve the accuracy and reliability of the chloride predictive tool, thereby providing a more technically robust evaluation of potential chloride impacts on Abercorn Creek due to harbor deepening.



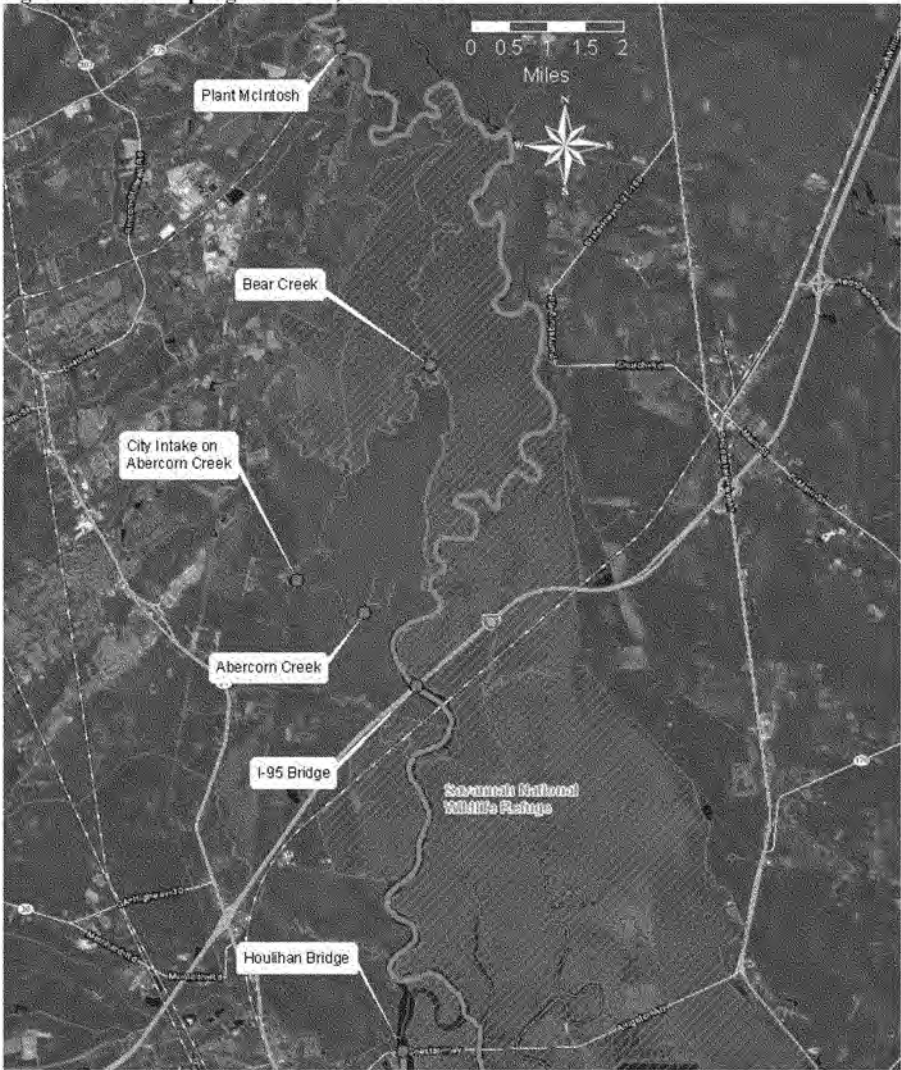
### 7.7.5 Data Collection

The Corps consulted with the City of Savannah to develop a scope of work for collection of additional chloride data that it could use to refine its tool to predict chloride levels with a harbor deepening. USGS and GPA also participated in development of the scope of work. Data was collected from early 2009 through summer 2010. The scope of work included collection of data using several techniques at multiple locations (see **Figure 7.7.5-1**), including:

- Abercorn Creek (flows, water surface, chloride, temperature, and conductivity)
- Bear Creek (flow, water surface, flow splits for Abercorn and Little Collis Creeks)
- I-95 Bridge (water surface, chloride, temperature, and conductivity)
- Houlihan Bridge (flow, water surface, chloride, temperature, and conductivity)
- Plant McIntosh (water surface, chloride, temperature, and conductivity)
- City Intake on Abercorn Creek (chloride)

Considerable effort was expended by Savannah District, USGS, and ERDC to collect additional data. Automated collection of samples at various locations followed by laboratory analysis of the samples proved successful. Efforts to record real-time chloride data were not successful due to unreliable field instruments. In addition to chloride data, velocity measurements and flow data were collected at Three Mouths, which is the confluence of Abercorn, Bear and Little Collis Creeks, in order to better calibrate the flow split in the hydrodynamic model at that location.

The Corps used this new data, the City's original chloride data, and subsequent daily chloride measurements collected by the City of Savannah to refine the modeling methodology.

**Figure 7.7.5-1: Sampling Locations, 2009 – 2010**

### 7.7.6 Updated Modeling Methodology

The new modeling methodology, development and calibration, is outlined in the report titled *Chloride Modeling Savannah Harbor Expansion Project Savannah, Georgia* prepared by Tetra Tech and Advanced Data Mining Services, dated December 31, 2010, and is included in the Engineering Investigations Supplemental Materials. The new model methodology has two parts: (1) an updated version of the EFDC model using an enhanced hydrodynamic grid to include the complicated distributary system of Abercorn Creek, and (2) an Artificial Neural Network (ANN) which uses data mining techniques. The two-pronged modeling approach provided both a mechanistic and empirical approach for predicting chloride concentrations at the City's intake and allows presentation of the findings in "bands" to better represent uncertainty associated with the data and the models. The two independent methodologies provided reasonably close agreement on chloride projections and are the best possible evidence of accuracy in the projections.

#### 7.7.6.1 Technical Review

An Agency Technical Review (ATR) was performed on the updated model methodology and the report titled *Chloride Modeling Savannah Harbor Expansion Project Savannah, Georgia* prepared by Tetra Tech and Advanced Data Mining Services. A South Atlantic Division Regional Technical Expert for Water Resources Engineering performed an ATR of the EFDC component and ERDC staff experienced with neural networks performed an ATR of the ANN component of the chloride model.

The Independent External Peer Review (IEPR) was conducted by Battelle, Inc. Dr. Andy Stoddard of Dynamic Solutions, LLC was the principal reviewer on the Battelle team for chloride analysis. Comments from these rigorous reviews were incorporated into the modeling and analysis for chloride SHEP impacts determination and the reviewers concluded that the models were applied appropriately for this purpose.

### 7.7.7 Chloride Impact Predictions

#### 7.7.7.1 Analysis of Daily Average Chloride Concentrations and Durations

Model predicted daily average and maximum daily average chloride concentrations are shown in **Table 7.7.7.1-1**. Results represent findings for two simulation periods.

The first period, 2003 to 2009, was simulated with both the EFDC and ANN models. This period was flood-free and included several prolonged drought periods, including the drought-of-record for the Savannah River Basin. Results represent impacts that could be expected during periods of extreme drought.

The second period, 1987-2009, and was simulated with EFDC only to determine the magnitude and duration of impacts over a more representative period of time and river flow conditions.

For the 1987-2009 simulation period, average chloride concentrations at the City's water intake would increase with all deepening alternatives, but the increase would be small, ranging from 0.2 to 2.9 mg/l (from the existing 10.6/10.8 mg/l). Maximum daily average chloride concentrations would also

increase with all deepening alternatives, ranging from 22 to 55 mg/l (from the existing 18 mg/l). All maximum values occurred during simulation of the drought of record (2008).

**Table 7.7.7.1-1: Daily Average and Maximum Daily Average Predicted Chloride Levels**

|                              | 1987-2009<br>typical river<br>flow       | 2003-2009<br>drought flow                             | 2008<br>drought of record <sup>4</sup>              |
|------------------------------|------------------------------------------|-------------------------------------------------------|-----------------------------------------------------|
| Project Depth<br>Alternative | Average Daily<br>Chloride<br>Level, mg/l | Average Daily<br>Chloride <sup>3</sup><br>Level, mg/l | Maximum Daily<br>Average<br>Chloride<br>Level, mg/l |
| Existing <sup>1</sup>        | 10.6                                     | 10.8                                                  | 18.3                                                |
| 44 ft Project                | 10.8                                     | 11.6                                                  | 40.9                                                |
| 45 ft Project                | 11.1                                     | 12.0                                                  | 48.6                                                |
| 46 ft Project                | 11.4                                     | 12.5                                                  | 53.6                                                |
| 47 ft Project <sup>2</sup>   | 11.7                                     | 13.1                                                  | 62.2                                                |
| 48 ft Project                | 12.2                                     | 13.7                                                  | 73.6                                                |

<sup>1</sup>Existing chloride value obtained from measurements observed by the City of Savannah.

<sup>2</sup>NED Plan

<sup>3</sup>Chloride values are averages of the ANN and EFDC approaches.

<sup>4</sup>All maximum values occurred during simulation of the drought of record. There are 80+ years of flow data in the record and the drought of record occurred in 2008.

As the daily laboratory testing of chlorides is performed on a 24-hour composite sample, so too are the daily chloride model projections presented above a composite of modeled hourly chloride values.

The maximum number of days that daily average chloride concentrations would be at or above a specified level for the 1987-2009 and 2003-2009 simulation periods are summarized in **Table 7.7.7.1-2**. Data shown for the existing channel condition is from daily sampling and laboratory analyses performed by the City of Savannah at their Port Wentworth water treatment plant. The chloride spikes would be caused by a combination of low flow and spring high tides.

**Table 7.7.7.1-2: Duration Using Daily Average Chloride Concentrations**

| Project<br>Depth<br>Alternative | Days Greater Than ...<br>% of Days Greater Than... |              |              |              |              |                                 |               |              |              |              |
|---------------------------------|----------------------------------------------------|--------------|--------------|--------------|--------------|---------------------------------|---------------|--------------|--------------|--------------|
|                                 | 2003-2009<br>drought flow                          |              |              |              |              | 1987-2009<br>typical river flow |               |              |              |              |
|                                 | > 5<br>mg/l*                                       | > 15<br>mg/l | > 25<br>mg/l | > 40<br>mg/l | > 50<br>mg/l | > 5<br>mg/l                     | > 15<br>mg/l  | > 25<br>mg/l | > 40<br>mg/l | > 50<br>mg/l |
| Existing                        | 2483<br>100%                                       | 26<br>1.0%   | 0<br>-       | 0<br>-       | 0<br>-       | 6705<br>100%                    | 111<br>1.7%   | 1<br>0.0%    | 0<br>-       | 0<br>-       |
| 44 ft<br>Project                | 2483<br>100%                                       | 252<br>10.1% | 39<br>1.6%   | 1<br>0.0%    | 0<br>-       | 8374<br>100%                    | 457<br>5.5%   | 52<br>0.6%   | 1<br>0.0%    | 0<br>-       |
| 45 ft<br>Project                | 2483<br>100%                                       | 331<br>13.3% | 72<br>2.9%   | 11<br>0.4%   | 0<br>-       | 8374<br>100%                    | 669<br>8.0%   | 91<br>1.1%   | 10<br>0.1%   | 0<br>-       |
| 46 ft<br>Project                | 2483<br>100%                                       | 413<br>16.6% | 112<br>4.5%  | 14<br>0.6%   | 4<br>0.2%    | 8374<br>100%                    | 853<br>10.2%  | 142<br>1.7%  | 19<br>0.2%   | 4<br>0.0%    |
| 47 ft<br>Project**              | 2483<br>100%                                       | 483<br>19.5% | 156<br>6.3%  | 31<br>1.2%   | 10<br>0.4%   | 8374<br>100%                    | 1051<br>12.6% | 219<br>2.6%  | 41<br>0.5%   | 11<br>0.1%   |
| 48 ft<br>Project                | 2483<br>100%                                       | 549<br>22.1% | 206<br>8.3%  | 54<br>2.2%   | 18<br>0.7%   | 8374<br>100%                    | 1301<br>15.5% | 330<br>3.9%  | 68<br>0.8%   | 23<br>0.3%   |

\*Background levels of chlorides are greater than 5 mg/l under all channel conditions.

\*\*NED Plan

Table 7.7.7.1-3 shows the percentage of time that chloride levels are projected to be above 25 mg/l and 50 mg/l for the existing 42-foot channel depth and the 47-foot depth for simulations for each year from 2001-2009. This period is not typical, as discussed previously in Section 7.7.4 and includes 2 prolonged extreme droughts, including the drought of record occurring in 2008.

**Table 7.7.7.1-3: Percentage of Days Each Year that Daily Average Chlorides are Greater Than 25 mg/l and 50 mg/l**

| Year | Chlorides > 25 mg/l     |                        | Chlorides > 50 mg/l     |                        |
|------|-------------------------|------------------------|-------------------------|------------------------|
|      | Existing<br>42 ft Depth | 47 ft<br>Project Depth | Existing<br>42 ft Depth | 47 ft<br>Project Depth |
| 2001 | 0%                      | 6%                     | 0%                      | 0.0%                   |
| 2002 | 0%                      | 5%                     | 0%                      | 0.0%                   |
| 2003 | 0%                      | 0%                     | 0%                      | 0.0%                   |
| 2004 | 0%                      | 2%                     | 0%                      | 0.0%                   |
| 2005 | 0%                      | 0%                     | 0%                      | 0.0%                   |
| 2006 | 0%                      | 0.2%                   | 0%                      | 0.0%                   |
| 2007 | 0%                      | 9%                     | 0%                      | 0.5%                   |
| 2008 | 0%                      | 17%                    | 0%                      | 2.2%                   |
| 2009 | 0%                      | 9%                     | 0%                      | 0.0%                   |

### 7.7.7.2 Analysis of Hourly Chloride Concentrations and Durations

The City has indicated that it is necessary to adjust some of its treatment processes on an hourly basis, and as a result, is concerned about hourly fluctuations in the chloride concentration at their raw water intake. Because there is limited mixing of the water as it moves through the Savannah I&D Water Plant process and the distribution pipelines, these hourly chloride projections are critical to the operation of the water plant.

The EFDC model used daily average chloride concentrations in its calibration process, which used data from 2001 through 2009. Since 2003, the City has analyzed chloride content of its intake water on a daily basis using a composite of samples taken hourly. Therefore, the chloride values upon which the updated EFDC model was calibrated represent a daily composite/average of hourly samples.

The District consulted with Tetra Tech, the developer of the updated EFDC model for chlorides, about the potential reliability of the EFDC calculations for hourly chloride values at the City's water intake. Tetra Tech concluded that although the daily average chloride value projections were derived from the hourly computed values, the model was not calibrated with the intent of generating hourly data and that the 90<sup>th</sup> percentile predicted chloride value is a more reasonable representation of the maximum short-duration chloride level likely to be experienced with the proposed harbor deepening project.

As a result, the District used the EFDC model to predict hourly chloride values at the City's water intake. In **Figure 7.7.7.2-1**, the green line indicates the hourly maximum predicted for the day, the yellow line is the daily average, and the blue line is the minimum hourly value predicted for the day. The predicted hourly peak of 185 mg/l is substantially higher than the maximum daily average of 62 mg/l. The predicted daily minimum remains at about 15 mg/l on that peak day. The peak 90<sup>th</sup> percentile chloride value is about 150 mg/l. The average being less than half the peak indicates that the lower chloride values have a longer duration than the higher chloride values. It also indicates that the high chloride levels are tidally dependent. When the tide ebbs, chloride levels are predicted to return to normal levels.

Model projections indicate that for the period 1987 – 2009, there would be 41 days where the average daily chloride concentration exceeds a threshold of 40 mg/l; however, hourly exceedances of 40 mg/l are projected to occur 445 days during this same period. Hourly exceedances of 40 mg/l typically occur 3 to 6 hours per day, with a maximum of 12 hours per day. We have little measured hourly chloride data for comparison, but the model projects that the 40 mg/l threshold has never been exceeded for even 1 hour under existing conditions.

**Figures 7.7.7.2-2 through 7.7.7.2-5** show the model predicted hourly output for the existing conditions and all deepening alternatives with and without the flow-altering mitigation plan. **Figures 7.7.7.2-3 and 7.7.7.2-5** are zoomed in to show the variation in chloride concentrations during the period of November 2008 when they are at peak levels.

Figure 7.7.2-1: Model Predicted Daily Maximum, Minimum and Average 2001 – 2009, 47 ft Project Depth with Mitigation

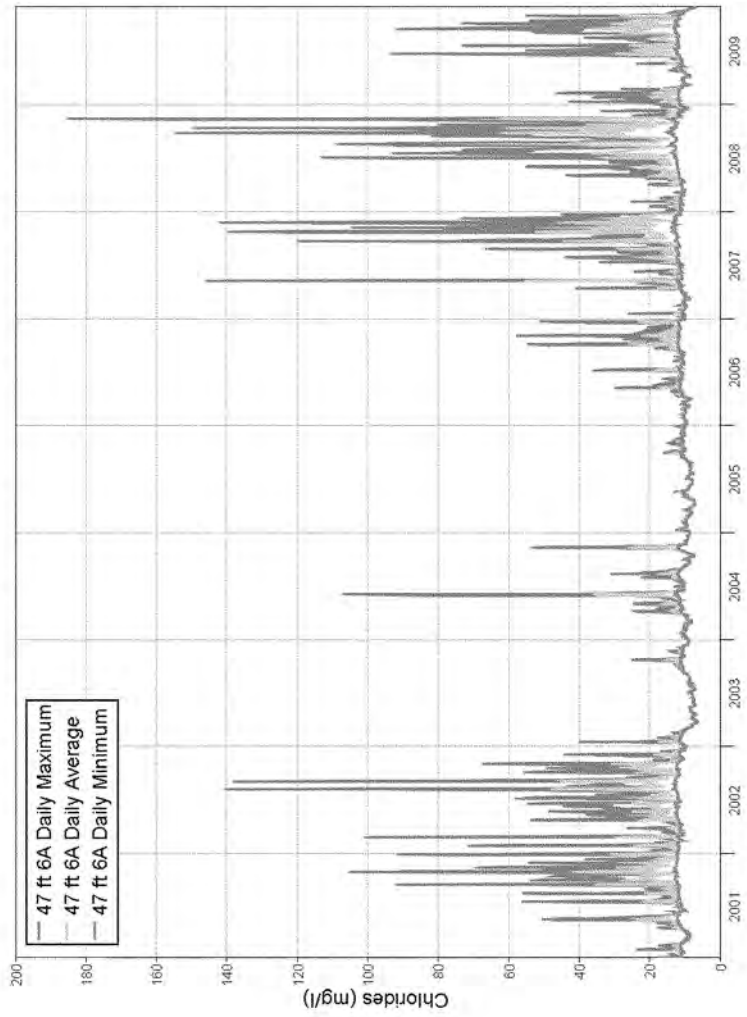


Figure 7.7.7.2-2: Model Predicted Hourly Output 2001 – 2009, Existing Conditions and All Project Depths (Deepening Only, No Mitigation)

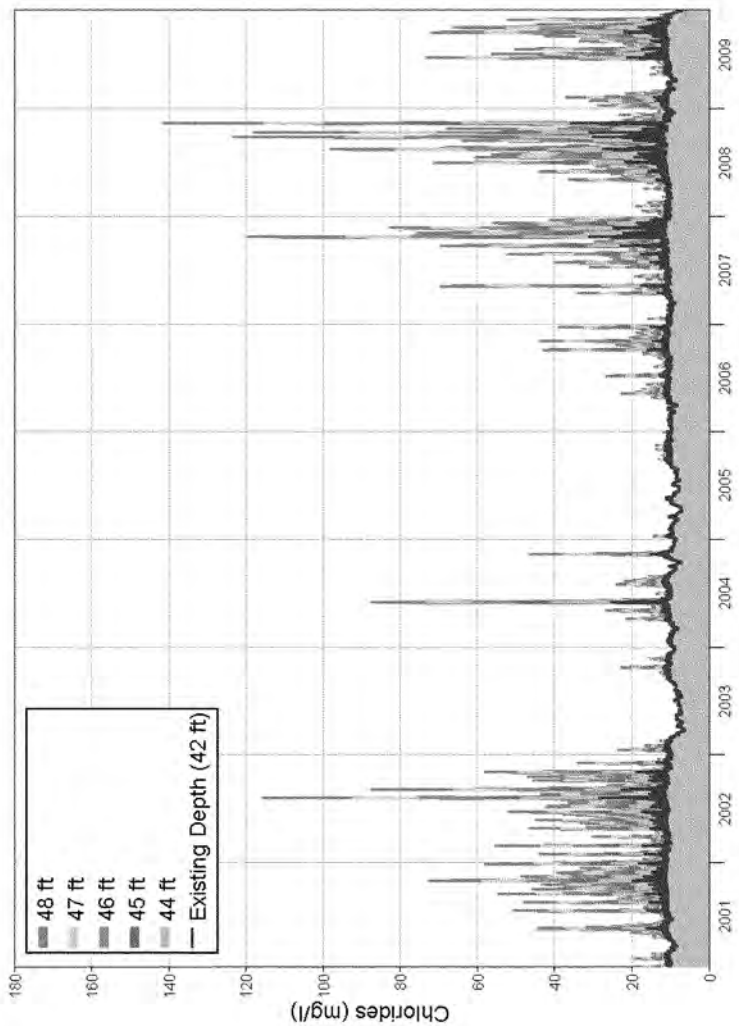




Figure 7.7.2-3: Model Predicted Hourly Output 2-17 November 2008, Existing Conditions and All Project Depths (Deepening Only, No Mitigation)

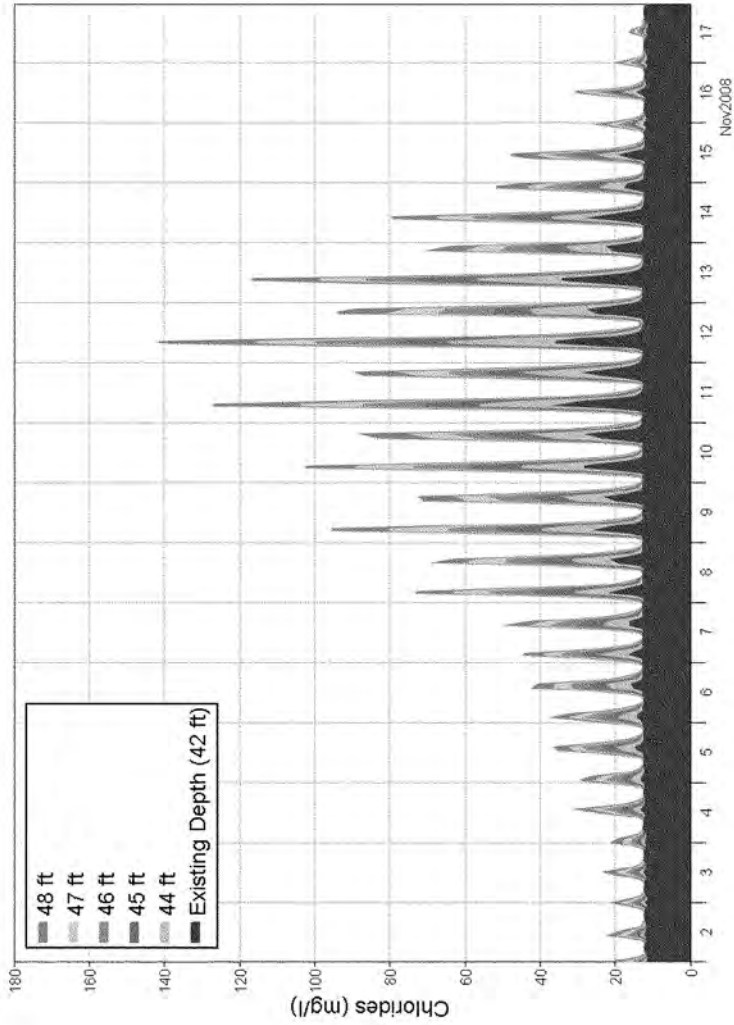


Figure 7.7.7.2-4: Model Predicted Hourly Output 2001 – 2009, Existing Conditions and All Project Depths (Deepening and Mitigation)

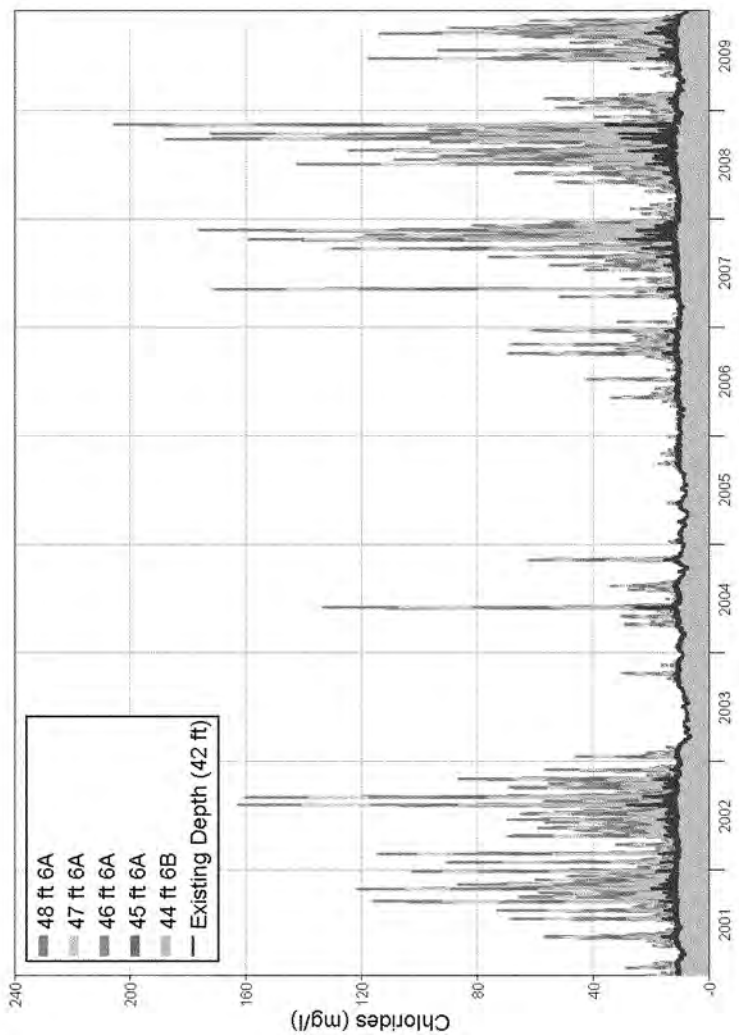
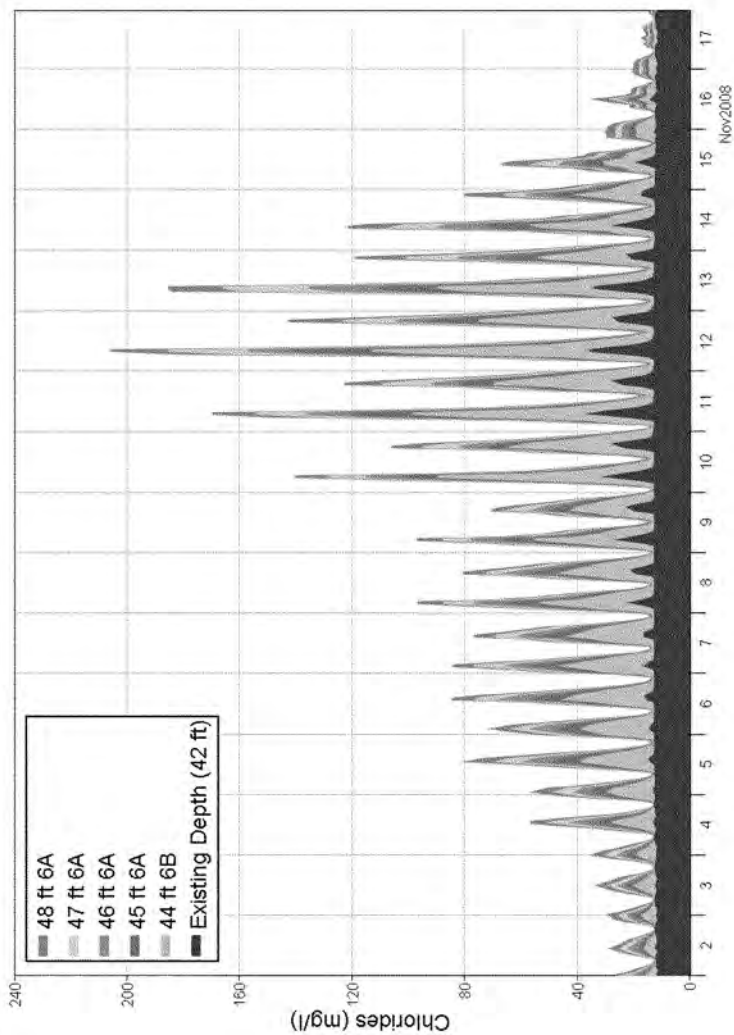


Figure 7.7.2-5: Model Predicted Hourly Output 2-17 November 2008, Existing Conditions and All Project Depths (Deepening and Mitigation)



### 7.7.8 Drinking Water Concerns

The Safe Drinking Water Act originally passed by Congress in 1974 authorizes EPA to set standards for drinking water quality to protect public health. Those standards are regulated and must be met by water suppliers to ensure drinking water is safe for human consumption. While the City of Savannah's water supply intake located on Abercorn Creek largely supplies water for industrial purposes, it also supplies municipal water and is regulated as such to ensure that the water is safe for drinking.

National drinking water regulations can be classified as primary or secondary and thresholds are specified by a maximum contaminant level (MCL). Primary standards protect public health by limiting the levels of contaminants in drinking water while secondary standards are aesthetic considerations and are not federally enforced.

The City's treatment facility in Port Wentworth currently treats approximately 30 million gallons of water per day (30 MGD) from Abercorn Creek before it is supplied to the distribution system. The plant's design capacity is 62.5 MGD and its current withdrawal permit from GA DNR-EPD is for 55 MGD.

#### 7.7.8.1 Chloride Predictions and Secondary Drinking Water Standards

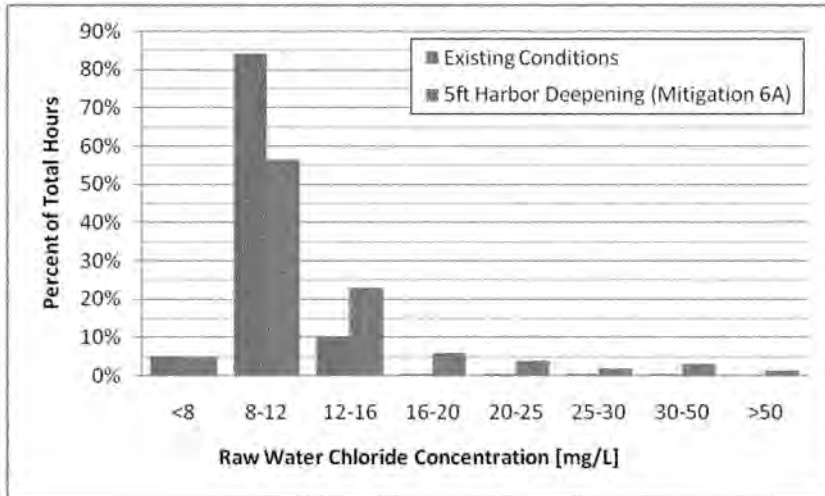
The updated impact analysis indicates that the proposed harbor deepening would increase chloride levels at the City of Savannah's water intake on Abercorn Creek under drought conditions during high tide. Under those conditions, maximum daily average chloride levels are predicted to be 62 mg/l with a maximum hourly chloride level projected as 185 mg/l for the 47ft project. However, the long term average chloride level is only predicted to increase from 11 to 13 mg/l. **Figure 7.7.8.1-1** shows a comparison of Model Output for Existing Conditions and 47 ft deepening with mitigation.

The National Secondary Drinking Water Standard for chloride is 250 mg/l. This level is established as a threshold of taste and odor detection and not as a health hazard. The predicted chloride concentrations with harbor deepening do not approach that threshold, even under the worst-case drought conditions (drought of record).

Savannah District contacted the chief of the Washington Aqueduct water system (a municipal water system operated by the Baltimore District, USACE for the Washington, DC area) regarding the anticipated impacts from this type of change in water chemistry on a water treatment system. The issue was discussed with Dr. Vern Snoeyink, a leading expert in the field of water treatment. Dr. Snoeyink is a Professor of Environmental Engineering at the University of Illinois and author of a commonly used college textbook on water chemistry. They cautioned the District to avoid using the Secondary Maximum Contaminant Limit of 250 mg/L as a relevant standard upon which to evaluate the merits of the water utility's concerns as it is a taste threshold. They also indicated a concern for the water supplier's ability to achieve "simultaneous compliance". The term "simultaneous compliance" refers to a situation where addressing one regulation threatens compliance with a different regulation. In the fall of 2000, Washington Aqueduct made a change in its disinfectant to address disinfection byproduct (DBP) issues, and as a result, unknowingly affected the corrosion control in the system that manifested itself in increased lead release from lead service lines and other fixtures more than three years later. They further stated "The changes can be very subtle on the front end, but the chemistry through the plant and into the distribution system is extraordinarily complex."

**Figure 7.7.8.1-1: Comparison of Model Output, Existing Conditions vs. 47 ft NED Plan with Mitigation**

### Model Predicted Chloride Concentrations at Abercorn Creek Intake



#### 7.7.8.2 Corrosion and Primary Drinking Water Standards

This section discusses concerns that increased chlorides could have on:

- Corrosion of steel water distribution pipes resulting in increased life-cycle costs for the pipe distribution networks.

In their February 2011, letter the City presented model results that show that corrosion rates of steel double for a chloride increase from 18 mg/l to 70 mg/l, on average, neglecting the influence of temperature. The City owns and maintains about 750 miles of water distribution pipeline, 60% of which is steel. They computed that a 12% decrease in life expectancy of pipelines, corresponded to an increased replacement cost of \$22 million.

- Corrosion of lead and copper which could lead to unsafe levels of copper and lead ions in the water.

National Primary Drinking Water Standards specify regulations for lead and copper through the Lead and Copper Rule. The Lead and Copper Rule is a Federal regulation which limits the concentration of lead and copper water suppliers can allow in public drinking water. It was issued by the US Environmental Protection Agency June 1991 pursuant to the Safe Drinking Water Act as amended. Lead and copper primarily enter the drinking water from corrosion of plumbing materials that utilize copper pipe and lead solder. Potential health risks can result from exposure to lead that can include brain, red blood cell, and kidney damage.

At the direction of the Savannah District, Arthur Freedman Associates performed an investigation and analysis of water system chloride concerns. This report, completed April 29, 2011, is titled *Assessment of Chloride Impact from Savannah Harbor Deepening* and is included in the Engineering Investigations Supplemental Materials. Their analysis included computer simulations (WatSim), which indicated that raising pH was a potential remedy for increased corrosion rate, and subsequent laboratory testing to confirm the model study. The conclusion of the Freedman analysis was that copper and lead corrosion were likely not an issue and that steel corrosion could be controlled by raising the pH of the treated water supplied to the distribution system. Their study also recognized that increasing pH to reduce corrosivity can result in the formation of disinfection byproducts (DBPs), such as trihalomethanes and bromates, which are suspected carcinogens and regulated by the National Primary Drinking Water Standards.

The Freedman report suggested additional laboratory analyses to confirm these conclusions. The GPA, in coordination with the District and the City of Savannah, contracted with Camp Dresser and McKee (CDM) to perform more detailed laboratory analyses on location at the water treatment plant that would replicate the City's current water treatment process and evaluate the impact of increasing chlorides on the plant water and treatment process including analysis of DBP formation. Their report titled *City of Savannah Seawater Effects Study* dated December 2011 which is included in the Engineering Investigations Supplemental Materials addressed concerns of the City's requirement for simultaneous compliance and presented evidence that there are two significant impacts to drinking water quality from increased chlorides – increased lead corrosion and formation of disinfectant byproducts (DBPs).

#### **7.7.8.2.1 Lead Corrosion**

Based on the laboratory analyses performed by CDM, lead corrosion is projected to increase considerably with increased chlorides. **Figures 7.7.8.2-1** and **7.7.8.2-2** show the effect of increased chlorides on lead, copper, and iron corrosion. They vary by the disinfectant used which mimics two distinct systems at the City's water treatment plant. While copper and iron concentrations were not shown to increase with increasing chlorides, lead concentrations in the water samples were shown to increase 2-4 times compared to the existing conditions as chloride concentrations increased from 10 mg/l to 50 mg/l. Also shown on these figures is the chloride to sulfate mass ratio (CSMR), which is a well documented indicator of corrosivity. Water utilities find this ratio useful as it can be measured at the plant prior to the water being exposed to metals within the distribution system. Research has shown that utilities with a CSMR ratio of 0.58 or less had greater tendencies to meet the action level for lead. This level is indicated by a red dashed line on **Figures 7.7.8.2-1** and **7.7.8.2-2**.

Figure 7.7.8.2-1: Lab Results of Chloride Effects on Metal Release (Free Chlorine Disinfectant)

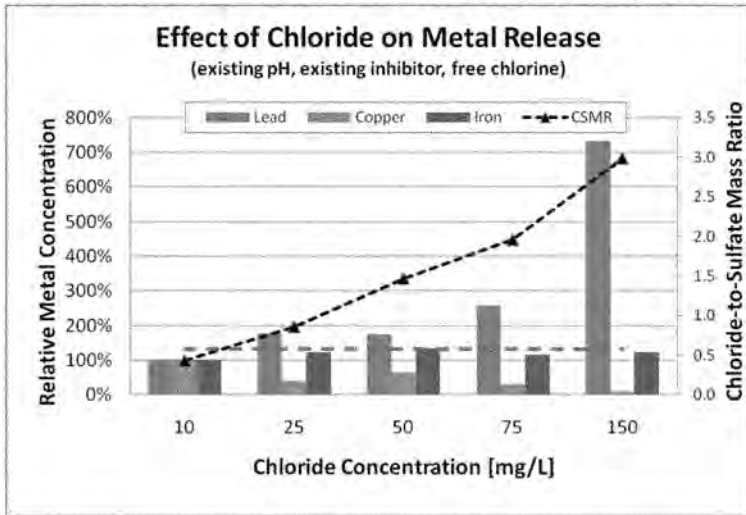
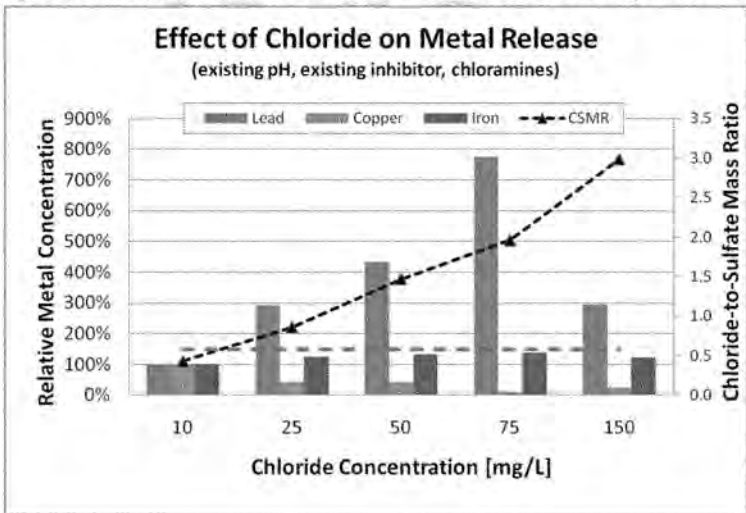


Figure 7.7.8.2-2: Lab Results of Chloride Effects on Metal Release (Chloramines Disinfectant)



Whether or not those increased levels will exceed regulatory action limits as defined by the Lead and Copper Rule cannot be determined with certainty due to the fact that regulatory sampling for lead is performed at the customer's tap and is highly dependent upon the customer's piping and the contact

time in that piping. Although there are Federal regulatory limits, as outlined by the Lead and Copper Rule for lead levels in drinking water, the ideal level is zero lead. That means that it is not acceptable to cause increases in lead levels as long as the regulatory threshold is not exceeded. Any increase in lead concentration is considered an increased health risk.

#### **7.7.8.2.2 Disinfection Byproduct Formation**

The City of Savannah uses free chlorine as a disinfectant against pathogens in their water treatment process, as do many water suppliers. It is an effective disinfectant and is available at a relatively low cost. However, free chlorine can react with dissolved natural organic matter present in the water to form byproducts. These disinfection byproducts (DBPs) can be classified as trihalomethanes (THMs) and haloacetic acids (HAAs) which are regulated under the Disinfectants and Disinfection Byproducts Rule (D/DBPR). The D/DBPR is a Federal regulation which limits the concentration of DBPs water suppliers can allow in public drinking water. It was issued by the US Environmental Protection Agency December 1998 pursuant to the Safe Drinking Water Act as amended. Potential cancer, reproductive and developmental health risks can result from exposure to DBPs. Through the D/DBPR, the USEPA MCL for total trihalomethanes is 80 µg/l and the five haloacetic acids are 60 µg/l. These are Primary Drinking Water Standards and violations require notifying the public as well as reporting to the State.

The CDM lab analysis showed that DBPs are affected by increasing chlorides in two ways:

Increasing chloride concentrations due to SHEP causes an increase in chlorine required to treat the water. (See **Figure 7.7.8.2.2-1**) The additional disinfectant required to achieve treatment goals causes the formation of additional byproducts.

As chlorides are pushed further upstream with harbor deepening, bromides, which are another component of seawater, are pushed further upstream as well. Brominated compounds can react with chlorine to form bromine-containing THMs, HAAs, and other byproducts. The rate of DBP formation is also affected by the presence of bromide in the source water.

Under both of these conditions expected to occur under SHEP, total THMs are projected to increase above the permitted level when chlorides exceed about 60 mg/l (See **Figure 7.7.8.2.2-2**). HAAs are not projected to increase above regulatory limits; however, the regulated species may be expanded in the future to include brominated HAAs, at which time the chloride impacts could affect compliance.



Figure 7.7.8.2.2-1: Lab Results of Chloride Effects on Chlorine Demand

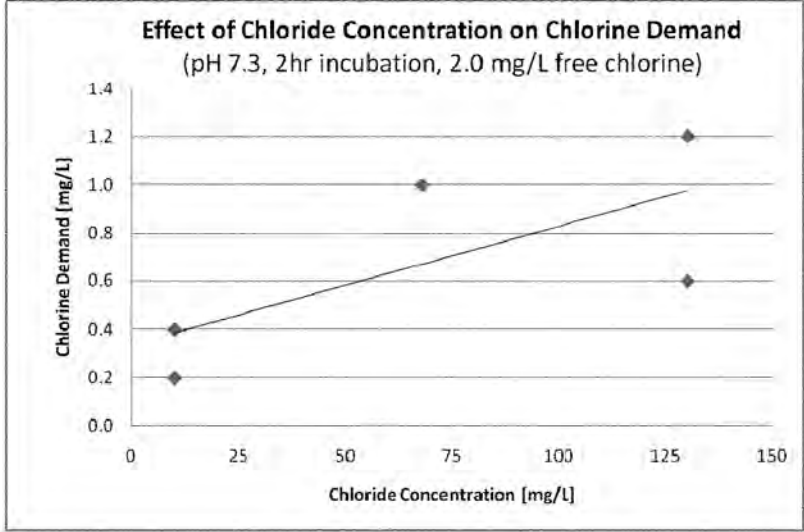
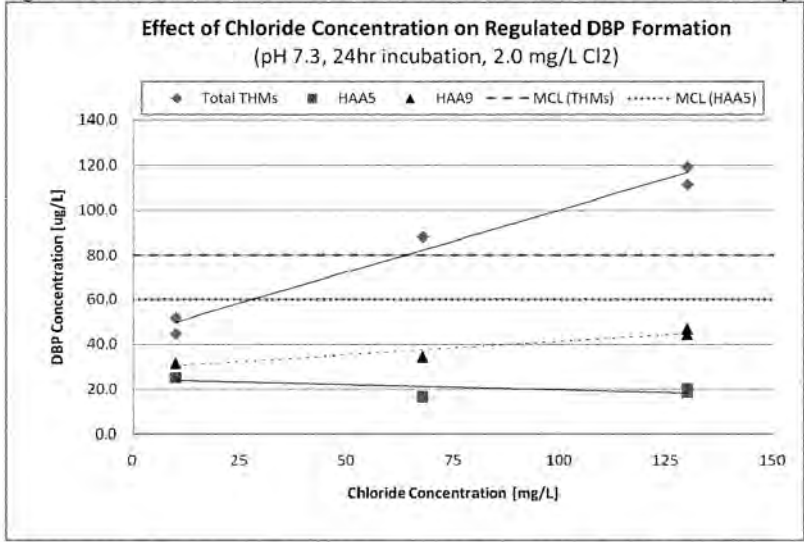


Figure 7.7.8.2.2-2: Lab Results of Chloride Effects on Formation of Disinfectant ByProducts



## 7.7.9 Industrial Water Supply Concerns

In a 2008 letter, the City of Savannah provided estimates of costs to the industrial users if chlorides were increased to 50 mg/l. The cost was very high but not considered to be representative since the increases to 50 mg/l are only projected to be occasional, not continuous.

### 7.7.9.1 Weyerhaeuser

Weyerhaeuser is the single largest user of the City's surface water supply; their demand is currently 12-13 MGD. Usage was higher, 15-16 MGD, before process water cooling towers were installed. The plant does not operate any groundwater wells. They use surface water supplied by the City supplemented by an intake they operate on-site near the Houlihan Bridge that draws 12-15 MGD of estuary water into the plant. The on-site intake water is used 1) in a large plant fire protection system and 2) to cool the black liquor surface condenser which operates with once-through cooling water. The intake is designed to draw water from near the surface; therefore, surface water model results most closely resemble the water used at the Weyerhaeuser intake.

The EFDC modeling predicts that the increase in surface water chlorides at the Houlihan Bridge is about 50% (See **Table 7.7.9.1-1**). The principal concern for the Weyerhaeuser surface water intake is a reduction in the lifespan of the water distribution system. Their water distribution system for water purchased from the City is entirely separated from their surface water withdrawal system.

**Table 7.7.9.1-1: Predicted Daily Average Chlorides (mg/l) at Houlihan Bridge**

|               | Surface Layer           |                        | Bottom Layer            |                        |
|---------------|-------------------------|------------------------|-------------------------|------------------------|
|               | Existing<br>42 ft Depth | 47 ft<br>Project Depth | Existing<br>42 ft Depth | 47 ft<br>Project Depth |
| 10 Percentile | 290                     | 570                    | 1,440                   | 7,200                  |
| 50 Percentile | 1,760                   | 2,460                  | 5,840                   | 11,760                 |
| 90 Percentile | 2,970                   | 3,890                  | 10,170                  | 15,460                 |

Weyerhaeuser uses the water they purchase from the City of Savannah for boiler water, industrial process water, and cooling water. Boiler water must be demineralized before use. The demineralizer system is currently running at 50 to 60% of capacity. Additional chlorides, as well as any lime or phosphate introduced to reduce corrosion, will increase the load on the demineralizer and slow the output. Mill cooling water is cooled in cooling towers and returned to the mill circuit; however, the amount of recycling is governed by the impurity concentration. An increase in chloride will result in fewer cycles of usage for the cooling water, thus requiring an increase in the supply from the City I&D plant. The major process use of City water is in the bleaching process. Chlorides interfere with the bleaching, so increases in chloride levels could create a serious problem. The plant has an on-site storage tank for about 11 hours usage of demineralized water. If the water supply quality does not meet their requirements for more than 11 hours, a plant shutdown would likely be needed. The hourly variation in chlorides, shown in Section 7.7.9.3, indicates that the on-site storage of demineralized water may be sufficient if they are able to refill the storage tank between chloride spikes.

### 7.7.9.2 International Paper

Unlike Weyerhaeuser, International Paper (IP) has no on-site surface water intake. They do, however, have on-site wells that produce about 15 MGD. In the next 5 to 10 years, IP expects to be required by the GA DNR-EPD to replace their groundwater supplies with surface water. The groundwater has a high level of silica, which provides a natural corrosion protection in their process water distribution system, but which also must be removed by a demineralizer prior to being used in the boilers. Since the surface water does not have high silica content, this would enable IP to have sufficient capacity to demineralize higher levels of chloride from the City water. However, IP is concerned about the integrity of their process water distribution system. Increased chlorides may result in an increased corrosion rate which could threaten the distribution system. Replacement of the piping system would likely be very costly due to the size of the system and the numerous facilities built above the pipelines since they were originally installed. Therefore, the potential impact at IP is limited to a reduced lifespan for the water distribution system.

### 7.7.9.3 Other Industrial Use

IP and Weyerhaeuser are the two largest water users that the City supplies, but there are other industrial users fed by the Abercorn Creek Plant, including firms located in downtown Savannah, Garden City, Port Wentworth, Pooler, and Effingham County. No data is available on these other users, but their chloride concerns can be expected to be similar, on a smaller scale.

## 7.7.10 Mitigation Options

Extensive updated modeling efforts to predict chloride increases by frequency, concentration, and duration along with multi-variable bench-scale laboratory analysis on-site at the City's treatment plant have lead to the conclusion that the solution to mitigate for the impacts due to chloride increases with harbor deepening is to remove the influence of the increased seawater intrusion. That can be accomplished two ways:

- **Supplemental Intake and Pipeline.** Construct a supplemental intake and pipeline that can draw water from further upstream on the Savannah River, above the area impacted by salinity and chloride intrusion predicted with harbor deepening. Constructing a new intake pipeline would take fresh water from the Savannah River more than 10 miles further upstream from the current location on Abercorn Creek where chloride levels remain relatively constant at around 8 mg/l. The proposed pipeline route is 8.7 miles long through Chatham and Effingham County to the intake site located near Plant McIntosh.
- **Storage Impoundment.** Construct an impoundment that will store acceptable raw water for use during chloride spike events predicted to occur during very low river flow and high tides.

The storage alternative was determined to be the more cost-effective option that mitigates against both increasing lead corrosion as well as increasing DBP formation predicted with harbor deepening and is discussed further in Section 7.7.11.

All mitigation options, in addition to the alternatives discussed above, that were identified and evaluated during the study process are shown below:

- Modified Water Treatment Process. Conceptual cost estimates for modified treatment process options were developed by Freedman and Associates. Their report titled *Assessment of Chloride Impact from Savannah Harbor Deepening* is included in the Engineering Appendix Supplemental Materials. Costs outlined in the Freedman and Associates report are based on treatment of 60 MGD and are preliminary costs typical for these types of systems. Potential treatment modifications include a lime storage and feed system (\$2.8 million), a granular activated carbon system (\$47.2 million), and an ozonation system (\$35.4 million), all at the city I&D plant. Freedman and Associates also developed cost options for reverse osmosis systems and demineralizer systems on-site at both Weyerhaeuser and International Paper, which vary by plant and expected flow rates and range from \$4.4 - \$30.9 million. Freedman and Associates analysis was based on water quality modeling and preliminary lab analysis. While results of their study are useful, they are not definitive and as a result they recommended further analysis be conducted regarding the corrosion of copper and lead resembling a larger on-site pilot scale study.

A primary objective of the subsequent CDM testing was to identify a chemical process that would reduce the increased seawater corrosivity to existing levels that would work well with the City of Savannah's existing treatment plant, their water supply demands and the site specific water chemistry of the source water in Abercorn Creek. CDM explored the treatment options outlined by Freedman and Associates as well as additional options. The results of the bench-scale study indicate that neither the existing corrosion inhibitor nor pH adjustment will consistently control lead corrosion. While there are chemical treatments that could potentially address the issue of DBP formation, they would not fully mitigate for increasing chlorides as lead corrosion would remain a problem. The only treatment solution that would address both lead and DBP formation issues is advanced treatment. Under advanced treatment the conventional treatment process is amended to incorporate a range of sophisticated membrane technologies such as nanofiltration or reverse osmosis. Both of these options would remove the precursors relating to corrosion and DBP formation prior to treatment. However, either option would be very costly both in capital costs and operation and maintenance costs. Capital costs have been estimated to exceed \$60 million.

- Increasing Freshwater Supply Through Bear Creek. The Bear Creek diversion structure allows a portion of freshwater from the Savannah River to be diverted down Bear Creek to Abercorn Creek providing improved water quality at the raw water intake. Bear Creek flows through a heavily wooded area which is part of the Savannah National Wildlife Refuge. Flow in Bear Creek is currently impeded by numerous fallen trees. Clearing and snagging would remove these trees and improve freshwater flow from the river. This option was shown to be effective when the Corps constructed the diversion structure in 2002 as part of the Lower Savannah River Basin Environmental Restoration Project. Clearing and snagging more of Bear Creek (than was included in the authorized Environmental Restoration Project) would be required for this measure to work effectively as a mitigation feature. Since the creek flows through the Savannah National Wildlife Refuge, approval from US Fish and Wildlife Service would be required, which would be contrary to their management plan of the refuge. This option would also require a high level of periodic maintenance (removal of fallen trees) to perform as intended.
- Desalinization. A conceptual cost estimate for desalinization treatment at the location of the four largest industrial users was developed using the methodology published by the US Department of the Interior. That estimated cost was \$135 million and was determined to be cost prohibitive.

- Groundwater Supplementation. Increasing the amount of groundwater withdrawal during times of potential chloride intrusion on Abercorn Creek. This would have to be offset by greater use of surface water during higher flow periods. The Georgia Department of Natural Resources Environmental Protection Division limits the amounts of groundwater withdrawn by municipalities, complicating the use of an alternate source of water during times of drought with accompanying high chloride levels. Additionally, the City's current water supply distribution system does not have the capacity to move large quantities of water from the wells currently in place throughout its network. Construction would likely require locating and installing new wells and amending the distribution network.
- Freshwater Flow Supplementation. Instituting a variable drought plan release from Thurmond Dam. However, this produces problems for water managers and water users such as the City of Augusta, Savannah River Site, and Plant Vogtle.
- A combination of increased groundwater withdrawal and greater releases from Thurmond Dam, as described above.
- Construction of a Sill at the Mouth of Abercorn Creek to Prevent Chloride Intrusion. Modeling results have shown, and field sampling has confirmed, that the Savannah River is well mixed (not stratified) at the mouth of Abercorn Creek. Therefore a partial sill would not be effective in halting chloride intrusion. A mechanical gated structure that fully blocks inflow from the Savannah River during chloride incursion events would be required. Environmental impacts to wetlands would be excessive, and access to the gate location would be an issue. This option was not recommended for detailed study.
- Replacement of Individual Plumbing Fittings That are the Source of Lead Contamination. It is very difficult to estimate the total number of homes and businesses that would require modification. Costs would vary significantly, with much higher costs to repair slab foundation homes. Real Estate easement administration would also be very costly. Costs are conservatively estimated at \$100 million, and this would not address the DBP issue.
- Use of Barges to Store Water for Supplemental Use. It would require approximately 160 water tanker barges to provide the necessary volume. The logistics of storing and maneuvering these barges on Abercorn Creek make this alternative unfeasible.

### 7.7.11 Proposed Mitigation – Raw Water Storage

The proposed mitigation alternative is a raw water storage impoundment which provides the means to store water for use by the City for drinking water supply during times of high chloride events. The proposed mitigation was selected as it is the least cost, environmentally acceptable plan that meets the project needs.

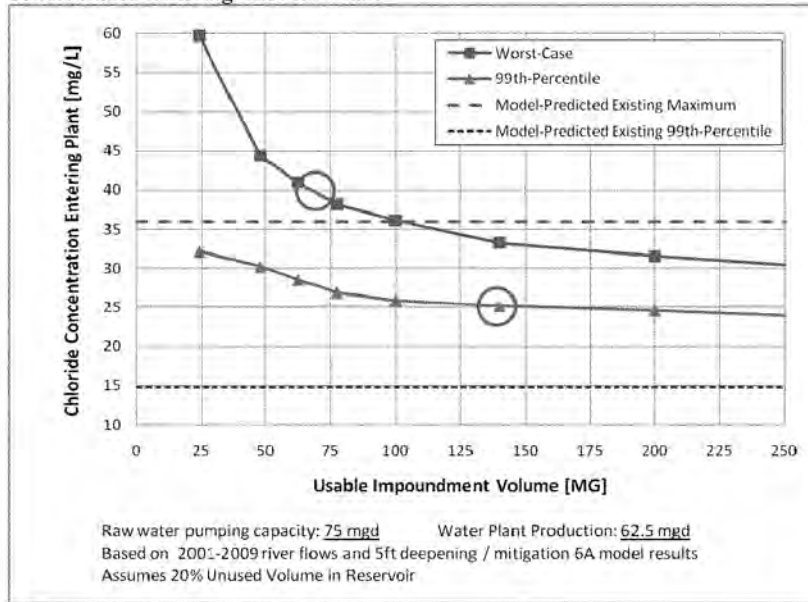
Design considerations for the raw water storage impoundment are:

- The GA DNR-EPD, in the Section 401 Water Quality Certification for Savannah Harbor Expansion, stated that any mitigation remedy selected shall be constructed in conjunction with the channel deepening. They also stated that mitigation shall be based on the maximum plant capacity of 62.5 mgd.

- A firm raw water pumping capacity of 75 mgd at the existing Abercorn Creek intake. Design constraints based on firm pumping capacity as opposed to the actual pumping capacity of 100 mgd is standard engineering practice and is required by the GA DNR-EPDs *Minimum Standards for Public Water Systems* published in May of 2000.
- 20% of the storage volume will be unusable due to access limitations and sedimentation.
- A performance goal of limiting the chlorides at the plant to 40 mg/l during the model predicted worst-case scenario and to 25 mg/l 99 percent of the time. As shown in the CDM lab analysis, 40 mg/l is the chloride concentration at which THMs in the distribution system can be expected to reach the MCL and potentially trigger a regulatory violation. Also shown in the analysis is that chloride concentrations as low as 25 mg/l have an adverse impact on lead corrosion.

A series of statistical analyses were used to determine the appropriate size for a raw water impoundment for use at the City's drinking water supply plant for all project depths under the design considerations noted previously. **Figure 7.7.11-1** shows the relationship between usable impoundment volume and the chloride concentration entering the I&D plant resulting from the statistical analyses. The dashed red and blue lines indicate the model-predicted maximum and 99th-percentile hourly chloride concentration under existing conditions, respectively. Each data point represents the concentration achieved when the impoundment is operated at the optimal pumping cutoff concentration, which varies by the size of the impoundment. Red circles indicate the minimum impoundment volumes needed to limit the maximum concentration to 40 mg/l and the 99th-percentile concentration to 25 mg/l, respectively. The area between the red circles represents the range of volumes recommended for consideration. Results of the analysis recommending an impoundment volume for each project depth are shown in **Table 7.7.11-1**.

**Figure 7.7.11-1: Relationship Between Usable Impoundment Volume And Chloride Concentration Entering The I&D Plant**



**Table 7.7.11-1: Proposed Raw Water Storage Impoundment Volumes Required for Each Project Depth Alternative**

| Project Depth | Recommended Usable Impoundment Volume, MG | Required Total Impoundment Volume, MG |
|---------------|-------------------------------------------|---------------------------------------|
| 44ft          | 22.5                                      | 28.0                                  |
| 45ft          | 30.0                                      | 38.0                                  |
| 46ft          | 46.5                                      | 58.0                                  |
| 47ft          | 77.5                                      | 97.0                                  |
| 48ft          | 120.0                                     | 150.0                                 |

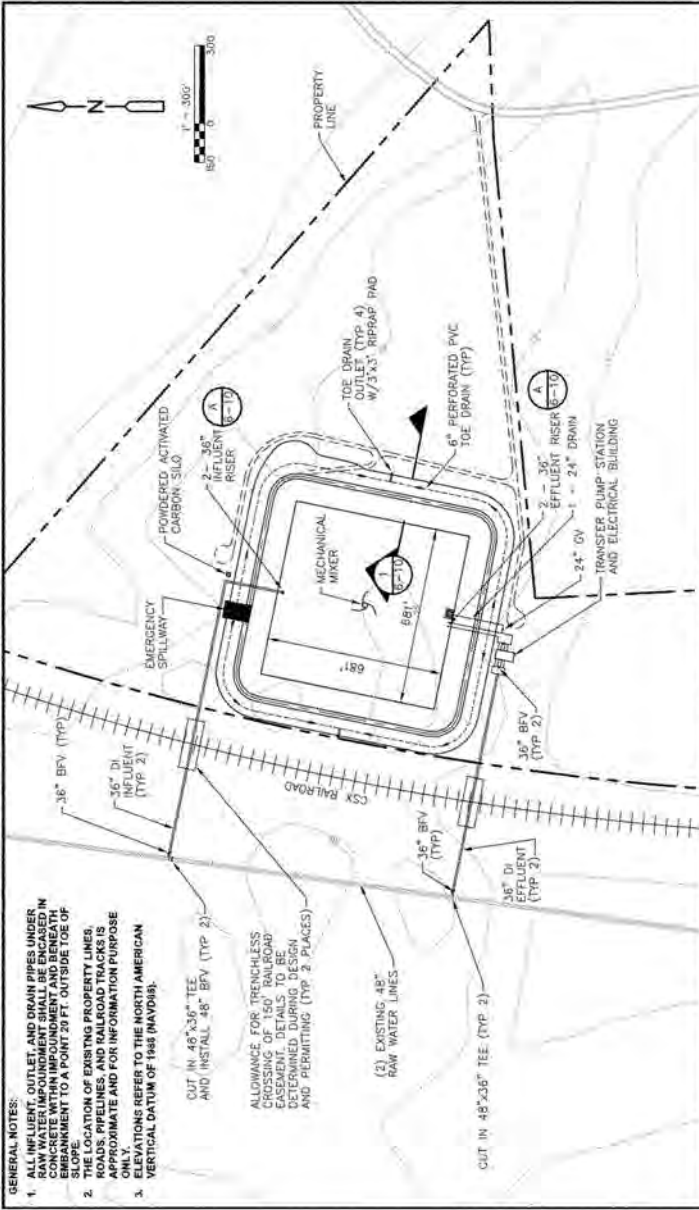
A conceptual site layout for the 47 ft depth alternative is shown in **Figure 7.7.11-1**. The preliminary layout and conceptual site plan includes the following (Details of the design can be found in the CDM report titled *City of Savannah Seawater Effects Study* included in the Supplemental Materials.):

- Dual 36" influent and effluent pipes to connect the impoundment to the existing raw water pipeline (to provide redundancy at the tie in points and allow for maintenance to occur during times when the impoundment is in use).
- A pump station containing four vertical turbine pumps to convey flow out of the impoundment and back into the raw water lines.
- A mechanical mixer in the center of the impoundment to help maintain oxygen levels throughout the impoundment's depth reducing the likelihood of algae growth and the associated taste and odor issues.
- A powdered activated carbon silo and feed system to be used on an intermittent basis during severe taste and odor episodes.
- A 24" drain pipe to be used to empty the impoundment during periodic maintenance cleaning.
- One or more in-situ chloride meters to be installed in Abercorn Creek to provide data for operational decision making.

Costs associated with this feature are detailed in Section 13.0



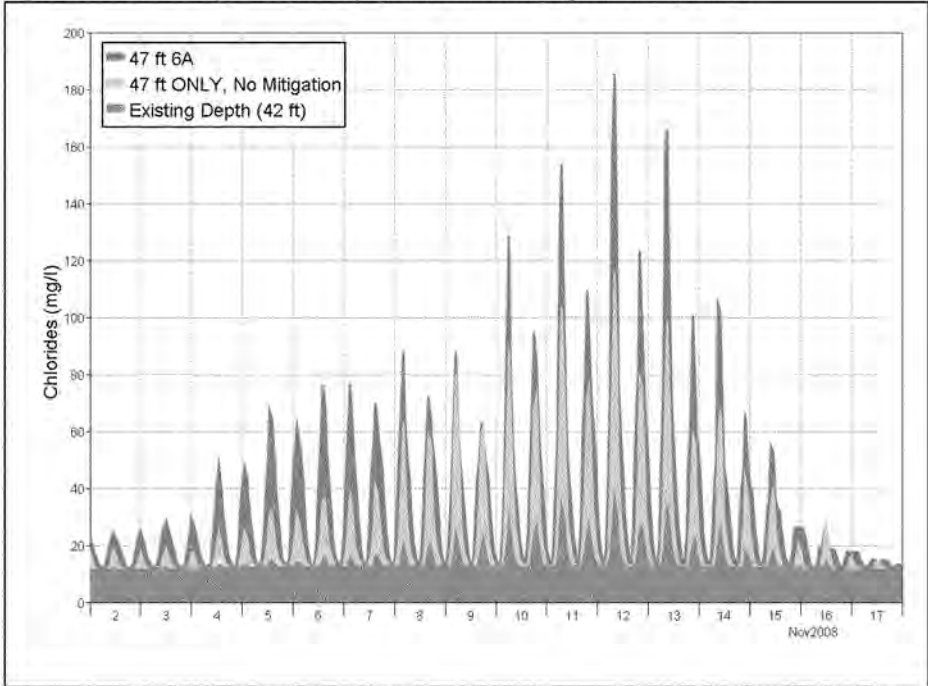
**Figure 7.7.11-1: Raw Water Impoundment Conceptual Site Layout**



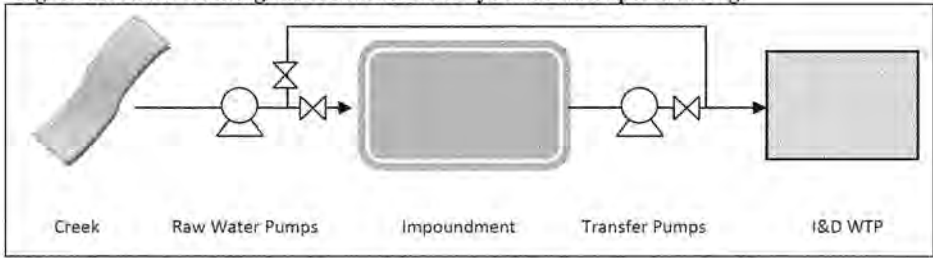
Conceptual Site Layout from City of Savannah Sewer Effects Study (CDM, 2011)

Model predictions indicate that high chlorides will occur diurnally, coincident with high tide. As shown in **Figure 7.7.11-2**, a plot of hourly projected chloride values during November 2008, chlorides return to levels of 12 to 15 mg/l twice each day, even on the peak day of predicted chlorides at 186 mg/l. An early warning system on Abercorn Creek will be required to provide data to the operator in a timely manner to know when valve and pump changes are needed.

**Figure 7.7.11-2: Hourly Chloride Projections Demonstrating Diurnal Variation**



Operation of the feature would require that water from the existing Abercorn Creek intake be utilized for treatment and pumped to the storage impoundment during occurrences of low chlorides. During occurrences of high chlorides, water from the impoundment will be pumped to the City's existing water treatment plant via the proposed pump station. During high chloride events at the intake, the intake pumps will be stopped and the plant will draw water from the storage impoundment thereby avoiding the high chlorides occurring in Abercorn Creek. When chloride concentrations on Abercorn Creek return to acceptable levels during low tide, the storage impoundment can be refilled and made ready for use during the next high tide. **Figure 7.7.11-3** illustrates the raw water piping and storage impoundment network.

**Figure 7.7.11-3: Flow Diagram of Water Intake System with Proposed Storage**

### 7.7.12 Conclusions

Analyses show that for normal to high river flows, there is expected to be very little change in chlorides from the existing condition for any of the deepening alternatives. However, for flows observed at the USGS Clio, GA streamgauge (RM 61) less than 6,000 cfs, the increases are statistically significant.

Mitigation to provide storage of raw water for use during high chloride events through a single impoundment optimized at 77.5 million usable gallons and the necessary supporting infrastructure is recommended. At the direction of the District, Tetra Tech has independently estimated the storage needs and has confirmed the size requirements. It is also recommended that the chloride mitigation feature be operational prior to completion of the channel deepening and the flow re-routing mitigation features associated with SHEP. Costs associated with construction of this feature are detailed in Section 13.0

Based upon flow conditions experienced in November 2008, the worst case event would require use of storage for 14 consecutive days. The total proposed storage volume represents only about 32 hours usage at plant capacity but the chloride content of Abercorn Creek will rise and fall with each tidal cycle; therefore, the impoundment will be partially refilled during low tide twice each day.

The October 1999 Chief's Report states that "If ... (a) chloride mitigation feature involving modification of the City of Savannah water supply system remains a part of the project, the costs of operation, maintenance, repair, replacement, and rehabilitation of the modified City of Savannah water system will remain a City of Savannah responsibility..." Based upon this language, it is anticipated that all O&M activities would be performed by the City of Savannah.

It is anticipated this mitigation proposal would be acceptable to the City of Savannah and the project sponsor.

## 8.0 MITIGATION DESIGN

### 8.1 MITIGATION FEATURES

This section includes the design and quantity determination of each flow-altering mitigation feature necessary for estimating construction costs. Costs for each feature are detailed in Section 13.0.

Sea level change guidance described in EC 1165-2-211 was considered in the design of the mitigation features. The structural design, resiliency and integrity of each mitigation feature was evaluated under the various sea level change estimates outlined in Section 7.5.2.2 of this Appendix. The resiliency and integrity of the design were considered to ensure the structures would not be compromised or produce unintended consequences under those various sea level projections. In addition, structural features would not pose a risk to public safety under any of the sea level change projections nor would their performance be adversely affected.

#### 8.1.1 Flow-Altering Mitigation Features (Plan 6a & 6b)

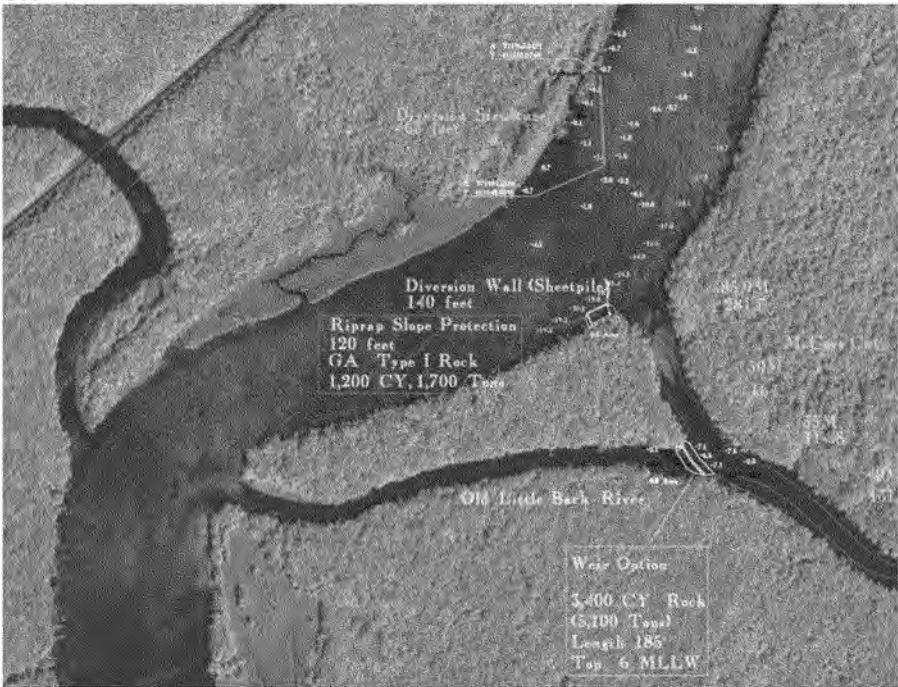
From the hydrodynamic modeling, Mitigation Plan 6a and 6b were developed. A summary of these flow-altering features along with the material quantities are summarized in **Table 8.1.1-1**. Design details of each feature are outlined following the table.

**Table 8.1.1-1: Material Quantities for Flow-altering Mitigation Features (Plan 6a & 6b)**

|    | Feature                                                          | Material Quantity                                      | Plan    |
|----|------------------------------------------------------------------|--------------------------------------------------------|---------|
| a. | Diversion Structure at McCoy Cut                                 |                                                        | 6a & 6b |
|    | Structure on northern river bank (465 ft long)                   | 5,400 tons GA Type I Riprap                            |         |
|    | Structure on southern river bank (140 ft long)                   | 1,700 tons GA Type I Riprap<br>12,100 sq ft Z-27 steel |         |
| b. | Closure of Lower (western) Arm at McCoy Cut                      | 5,100 tons GA Type I Riprap                            | 6a & 6b |
| c. | Deepening McCoy Cut to Middle River/Little Back River Confluence | 60,000 cy excavated                                    | 6a only |
| d. | Deepening upper Middle River                                     | 181,200 cy excavated                                   | 6a only |
| e. | Deepening upper Little Back River                                | 74,000 cy excavated                                    | 6a only |
| f. | Closure of Rifle Cut                                             | 2,500 tons GA Type I Riprap<br>3,300 cy fill           | 6a & 6b |
| g. | Sediment Basin Broad Berm (Weir)                                 | 97,000 tons GA Type I Riprap                           | 6a & 6b |
| h. | Sediment Basin Broad Berm (Fill)                                 | 1.2 million cy sandy material<br>from 12A              | 6a & 6b |
| i. | Removal of Tidegate Abutments & Piers                            |                                                        | 6a & 6b |
|    | Northern abutment                                                | 240,000 cy excavated over<br>2 acres                   |         |
|    | Southern abutment                                                | 785,000 cy excavated over<br>15.8 acres                |         |

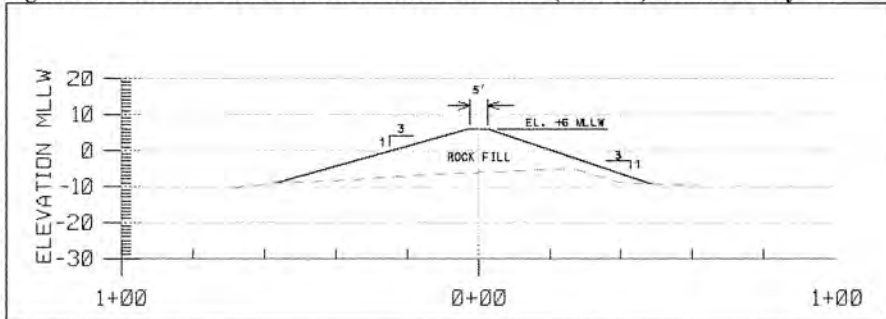
- a) **McCoy Cut Diversion Structure**– The McCoy Cut diversion structure is shown in **Figure 8.1.1-1**. The design for the diversion structures actually specifies two structures, a diversion structure constructed of rock and a diversion wall constructed of sheet pile and rock. Quantity estimates for the diversion structure upstream of McCoy’s Cut are 5,400 tons GA Type I Riprap, top elevation 0 MLLW. The diversion wall at the mouth of McCoy Cut specifies 140 ft length of sheet pile (9,800 sq ft steel Z-27 +2,300 sq ft Z-27 Buttress at 9 ft intervals), top elevation 11 ft MLLW, and 1,700 tons GA Type I Riprap.
- b) **Closure at Lower (western) Arm at McCoy Cut** – The weir structure at the closure on Lower (western) Arm at McCoy Cut (also shown in **Figure 8.1.1-1**) requires 5,100 tons of GA Type I Riprap. Top elevation is 6 ft MLLW. The center cross section of the closure structure is shown in **Figure 8.1.1-2**.

**Figure 8.1.1-1: McCoy Cut Diversion Structure and Closure at Lower (Western) Arm at McCoy Cut**



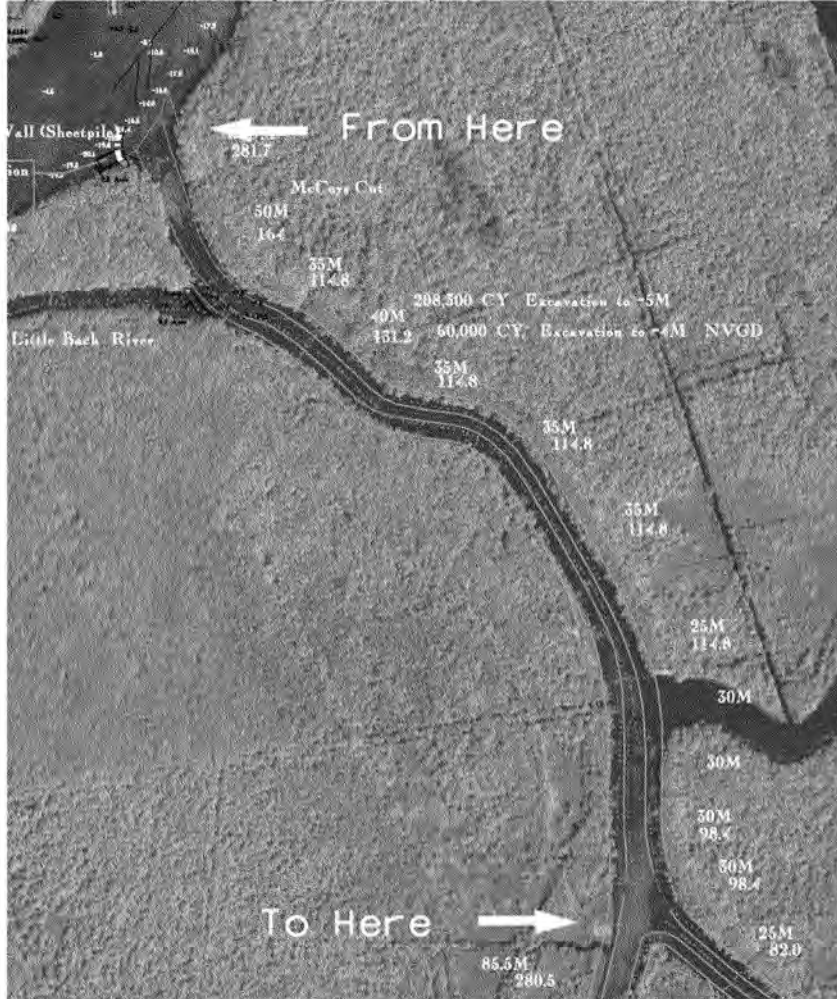
*\*The Lower (western) Arm at McCoy Cut is also known as Old Little Back River.*

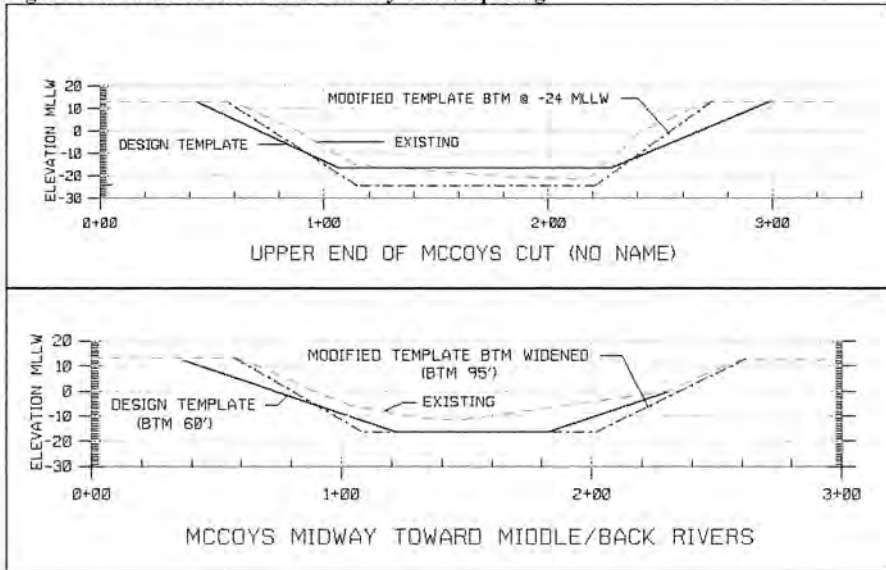
**Figure 8.1.1-2: Center Cross Section at Closure at Lower (Western) Arm at McCoy Cut**



- c) Channel Deepening on McCoy Cut – Drawings for the plan to deepen McCoy Cut and the river portion above the Middle/Little Back River confluence are shown in **Figure 8.1.1-3**. The total length of this portion is 1600 meters (5250 ft). Deepening to -4 m NGVD (-10.0 ft MLLW), as specified by the hydrodynamic model, will require 60,000 cubic yards of excavation. Two cross sections, where the template was modified to avoid taking of real estate, are shown in **Figure 8.1.1-4**.

**Figure 8.1.1-3: Channel Deepening on McCoy Cut**

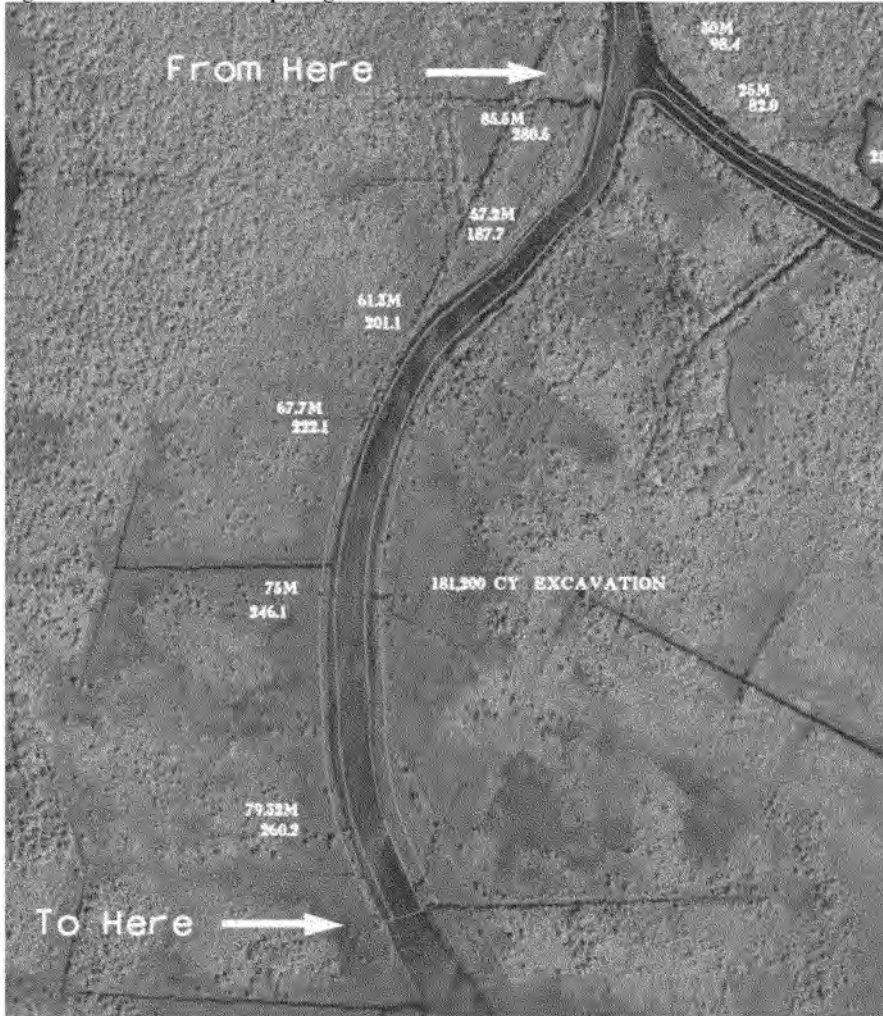


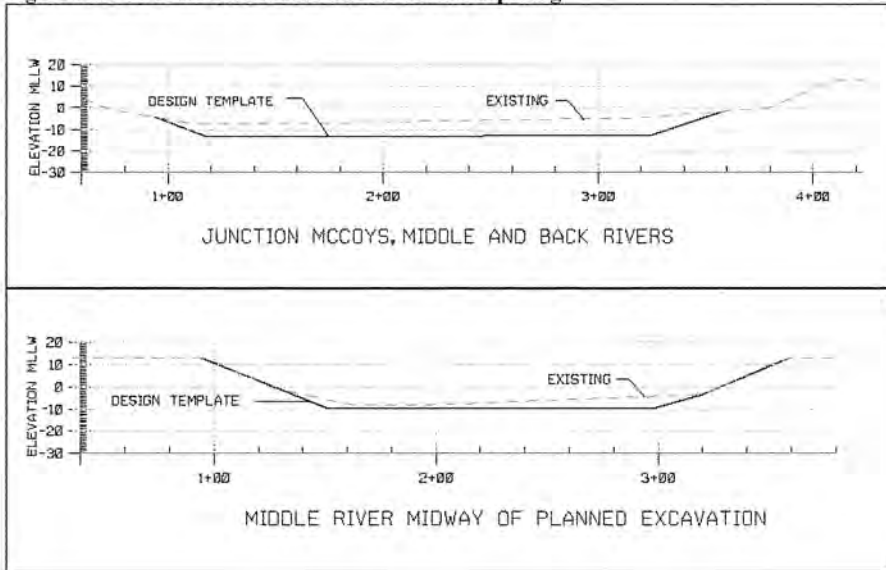
**Figure 8.1.1-4: Cross Sections for McCoy Cut Deepening**



- d) Channel Deepening Upper Middle River – The channel deepening on Middle River is for a distance of 1700 meters (5580 ft) and is deepened to a depth of -3 m NGVD (-6.8 ft MLLW), which requires 181,200 cubic yards of excavation. See **Figure 8.1.1-5**. Two cross sections are shown in **Figure 8.1.1-6**, one at the confluence and one on Middle River midway of the planned excavation.

**Figure 8.1.1-5: Channel Deepening on Middle River**



**Figure 8.1.1-6: Cross Sections for Middle River Deepening**

- e) Channel Deepening Upper Little Back River – The channel deepening on Little Back River is for a distance of 1700 meters (5580 ft) and is deepened to a depth of -3 m NGVD (-6.8 ft MLLW), which requires 74,000 cubic yards of excavation. See **Figure 8.1.1-7**. A cross section is shown in **Figure 8.1.1-8**, on Little Back River midway of the planned excavation.

**Figure 8.1.1-7: Channel Deepening on Little Back River**

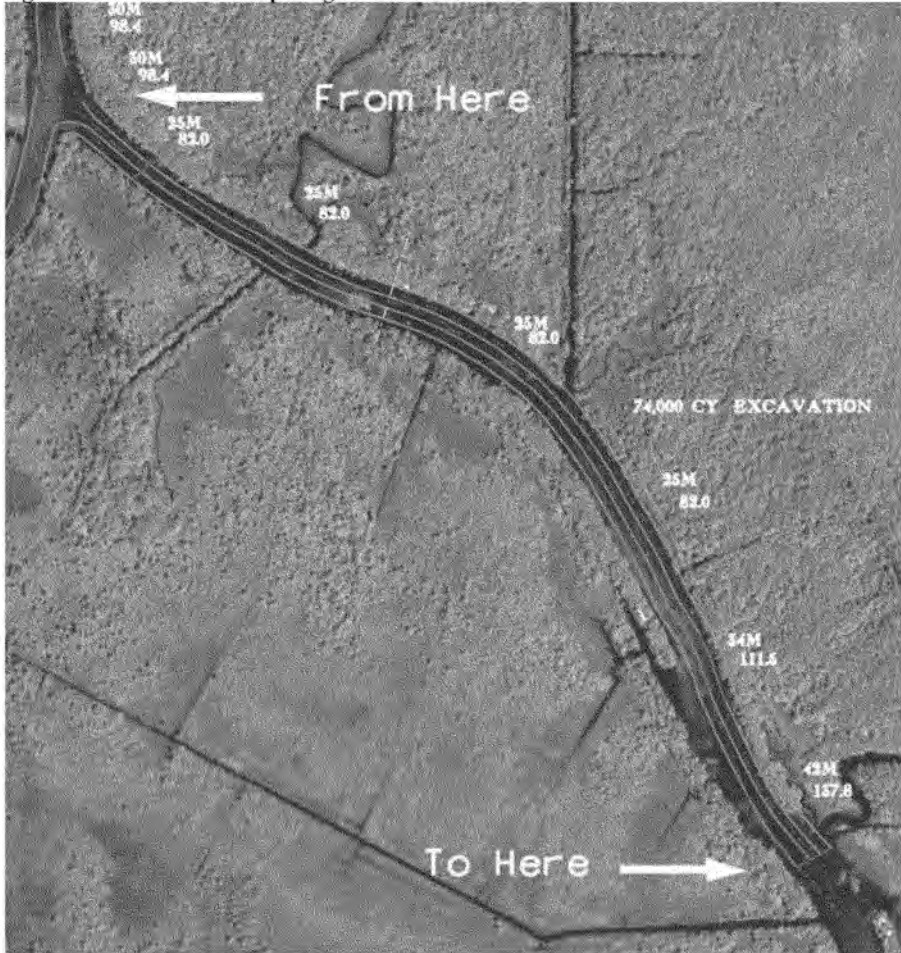
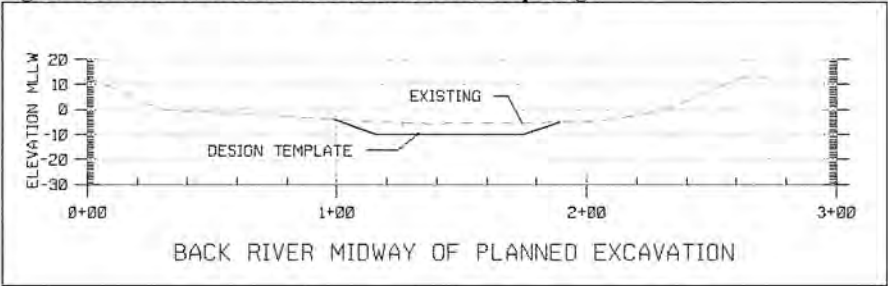


Figure 8.1.1-8: Cross Section for Little Back River Deepening

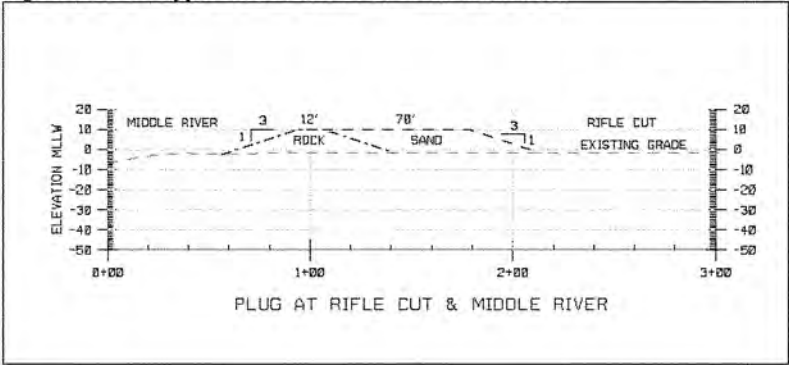


- f) Closure of Rifle Cut – Closing Rifle Cut involves constructing a plug at Middle River. The required easement is 30 ft beyond the work zone. The estimated quantities are 2,500 tons GA Type I Riprap and 3,300 cy of estimated fill. See **Figure 8.1.1-9** for an overview and **Figure 8.1.1-10** for a typical cross section.

**Figure 8.1.1-9: Closure at Rifle Cut**

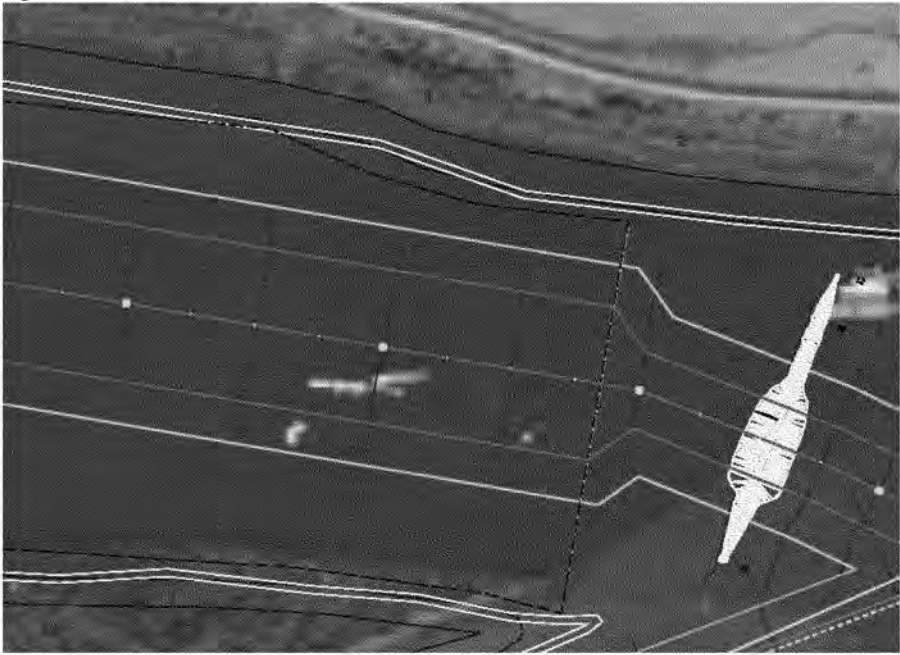


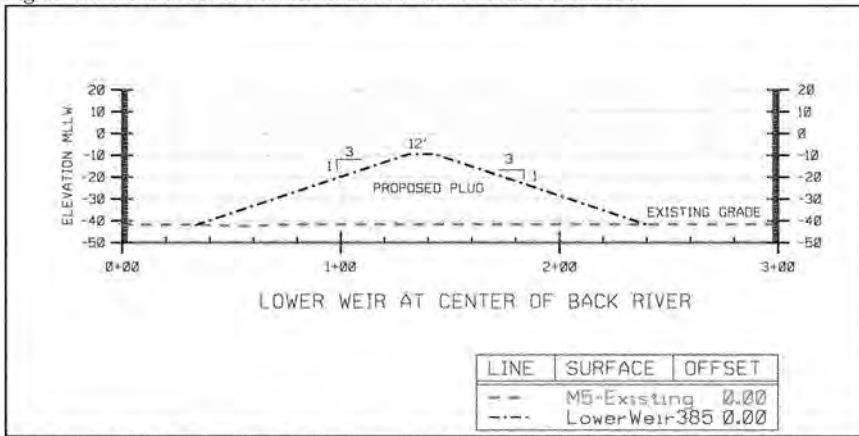
**Figure 8.1.1-10: Typical Cross Section for Rifle Cut Closure**



- g) **Sediment Basin Broad Berm (Weir)** – Filling the sediment basin to elevation -3.85 m NGVD (-9.5 ft MLLW) requires construction of a broad berm across the Back River at the Back River/Front River confluence. The broad berm consists of a weir which will require 97,000 tons GA Type I Riprap. See **Figure 8.1.1-11** for an overview plan of the broad berm weir and **Figure 8.1.1-12** for a cross section of the weir.
- h) **Sediment Basin Broad Berm (Fill)** – The broad berm is designed to eventually trap about 9.2 million cubic yards of sediment upstream to the tidegate sill at elevation -3.85 m NGVD (-9.5 ft MLLW). Once all the material is deposited to elevation -3.85 m NGVD, this mitigation feature will be considered fully functional as the design intended. To accelerate the rate of accumulation of sediments, approximately 1.2 million cubic yards of sandy material are to be placed behind the broad berm weir (within the Sediment Basin) after it is completed. This material would likely come from the construction of two other mitigation features (removal of the tidegate abutments and restoration of disposal area 1S) if that material is found to be suitable. The remaining volume needed to complete construction of the broad berm will be harvested from the interior of adjacent existing upland disposal areas.

**Figure 8.1.1-11: Sediment Basin Broad Berm Weir**



**Figure 8.1.1-12: Cross Section of Sediment Basin Broad Berm Weir**

*Note: Left of the drawing is Back River toward the tidegate, right is toward Savannah River.*

- i) **Removal of Tidegate Abutments & Piers** – This feature requires removal of 15 concrete piers and concrete walkway to the sill elevation (-3.85 m NGVD or -9.5 ft MLLW). The sill will be left in place. Removal of the abutments, existing armor stone, existing dock, stacked gates and hardware, pump building and contents, 2 other minor structures, and relocation of utility poles with electric and phone lines is also required. The north abutment excavation requires removal of 240,000 cubic yards over 2 acres. Removal of the south abutment requires excavation of 785,000 cubic yards over 15.8 acres. Real estate will be required for this feature. See **Figure 8.1.1-13** for the taking areas designated by the white line.

**Figure 8.1.1-13: Removal of Tidegate Abutments & Piers**





### 8.1.2 Fish Passage at New Savannah Bluff Lock & Dam

The New Savannah Bluff Lock & Dam (NSBL&D) is located on the Savannah River at River Mile 187.4, approximately 13 miles downstream from the City of Augusta, Georgia. See **Figure 8.1.2-1**. This facility is the most downstream lock and dam along the Savannah River and is authorized for the purpose of improving the commercial navigation channel between the upper limits of the Savannah Harbor and the head of navigation at Augusta, Georgia. It was constructed by the Corps and was completed in 1937.

The dam structure is 360 ft long and contains five vertical spillway gates. The lock is located along the right abutment (Georgia Side) and measures approximately 56 ft wide and 360 ft long, with a maximum lift height of approximately 15 ft. The facility provides ponding upstream to support several water intakes and recreation.

While commercial traffic no longer passes through the lock, some small recreation vessel locking is provided. The facility provides little in the way of flow retention or river regulation. The project no longer serves its original authorized purpose (navigation). It is now serving other useful purposes, water supply and recreation. There are concerns that the Lock and Dam remains an obstacle to migration of spawning fish. No Shortnose sturgeon (SNS) passage has been documented at the site since the dam was constructed. Providing fish passage at this location would restore access to historic SNS spawning areas at the Augusta Shoals.

**Figure 8.1.2-1: New Savannah Bluff Lock & Dam**



A fish passage facility at the NSBL&D is proposed as a mitigation measure for adverse impacts to the Shortnose sturgeon, a federally listed endangered species. Salinity increases due to SHEP lead to a loss in acceptable SNS winter habitat. Incidental improvements in dissolved oxygen lead to increases in less abundant SNS summer habitat. The Corps and the natural resource agencies could not identify any acceptable mitigation in the harbor or estuary for those impacts.

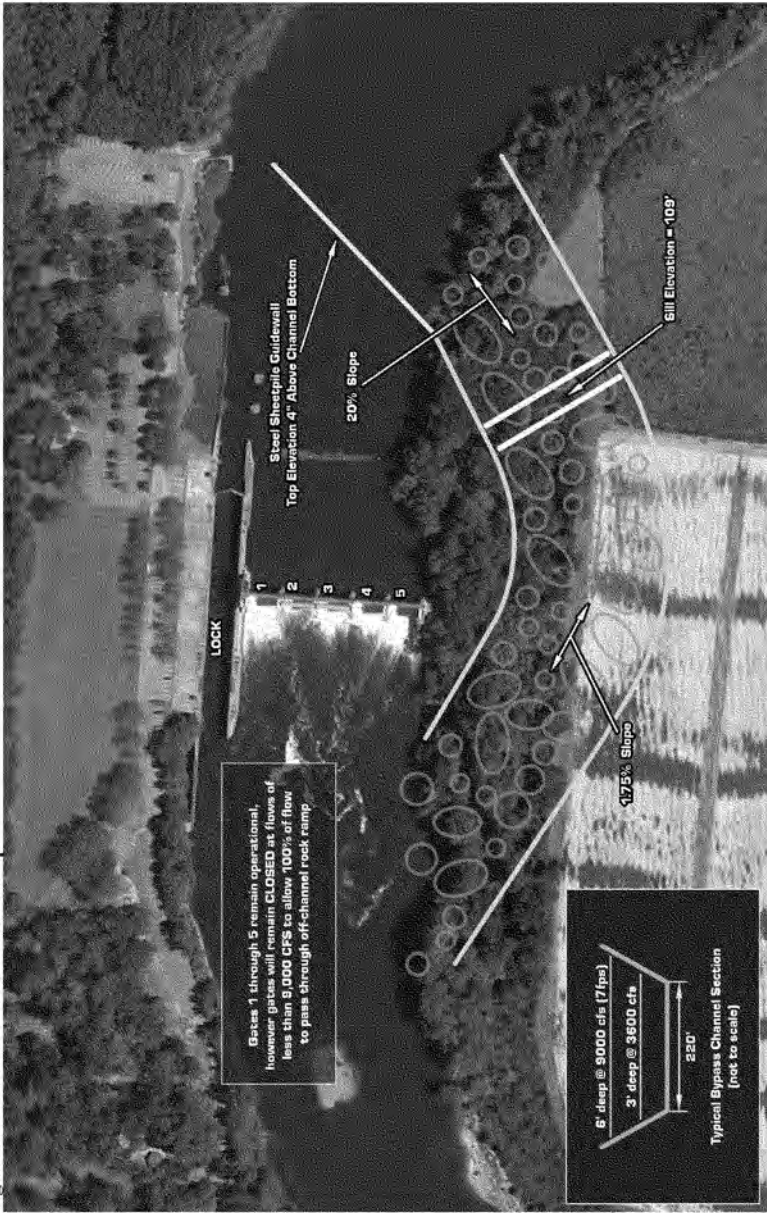
In the November 2010 draft SHEP GRR and EIS, the Corps proposed a Horseshoe Rock Ramp Bypass around the South Carolina side of the NSBL&D to provide fish passage past that structure, which is the first dam fish encounter as they move up the Savannah River to spawn. The Horseshoe Bypass would capture 5 percent of the river flow. The Feasibility Study for the Horseshoe structure along with preliminary Design and Cost Estimates are included in the Engineering Investigations Supplemental Materials. The two reports are titled, *New Savannah Bluff Lock and Dam Project Savannah River Georgia and South Carolina Fish Passage Facility Engineering Report* prepared by Framatome ANP DE&S, Inc. and *Revised 35% Design Construction Cost Estimate New Savannah Bluff Dam Fish Passage Facility* prepared by BTG, Inc.

During review of the Draft SHEP documents, the Corps received comments from natural resource agencies expressing a lack of confidence in the success of the Horseshoe Bypass design. Several stated that they believed the bypass would need to carry more of the river flow to successfully pass SNS. During an April 2011 interagency workshop, several potential SNS mitigation features were considered, including removal of the dam. After screening the alternatives within the Corps and with the resource agencies, a revised off channel rock ramp was selected and is now incorporated in the project as a mitigation measure for adverse impacts to SNS. The fish passage structure design described below includes refinements that go beyond the alternatives analysis completed during the summer of 2011. To achieve mitigation goals regarding flow velocities and depths through the structure, the design will be further refined during the PED phase.

The Off-Channel Rock Ramp (See **Figure 8.1.2-2**) consists of a rock ramp constructed around the South Carolina side of the lock and dam. All five gates will remain operational to allow for adjustments in the pool during high water events. Gates 1 and 5 require structural modification so that they function as lift gates rather than overflow gates. These modifications allow for 100% of the flow to pass through the fishway up to a river flow of 9,000 cfs. Flows over 9,000 cfs would flow through the gates on the dam. Based on a flow frequency analysis, this design would accommodate 100 % of the river flow for up to 71 % of the days of February through June. In the late spring months of May and June, when downstream passage is more critical, the 100 % flow capacity of the Off-Channel Rock Ramp increases to 83 % of the time. The range of river flows is shown in **Table 8.1.2-1**.

The velocities expected on the ramp vary depending on river flows ranging from approximately 5.5 feet/second at flows of 3,100 cfs to about 8.6 feet/second at 10,000 cfs. These are average velocities and depths; placement of numerous rock boulders to form pools up the rock slope will provide areas or pockets of lower velocity. During the design phase, a low section that connects the pools will be incorporated which will increase the maximum depth by at least a foot over the average depth shown in **Table 8.1.2-1**.

Figure 8.1.2-2: Off-Channel Rock Ramp



**Table 8.1.2-1: Off-Channel Rock Ramp Flow Frequency**

| Flow (cfs) | Upper Pool Elevation (feet) | Depth of Flow Over Rock Ramp (feet) | Percent of Flow | Velocity at Crest (fps) |
|------------|-----------------------------|-------------------------------------|-----------------|-------------------------|
| 3,100      | 112.1                       | 2.3                                 | 100%            | 5.5                     |
| 3,600      | 112.4                       | 2.5                                 | 100%            | 5.9                     |
| 4,300      | 112.8                       | 2.8                                 | 100%            | 6.3                     |
| 5,000      | 113.1                       | 3.0                                 | 100%            | 6.6                     |
| 6,000      | 113.6                       | 3.4                                 | 100%            | 7.1                     |
| 8,000      | 114.5                       | 4.0                                 | 100%            | 7.9                     |
| 10,000     | 115*                        | 4.6*                                | 94%*            | 8.6*                    |
| 12,000     | 115*                        | 4.6*                                | 78%*            | 8.6*                    |
| 15,000     | 115*                        | 4.6*                                | 63%*            | 8.6*                    |
| 20,000     | 115*                        | 4.6*                                | 47%*            | 8.6*                    |
| 25,000     | 115*                        | 4.6*                                | 38%*            | 8.6*                    |
| 30,000     | 115*                        | 4.6*                                | 31%*            | 8.6*                    |

\*estimated values

The rock ramp design is sloped up to a minimum crest elevation of elevation 109 ft at a 1.75% slope (1:50) on the downstream side and a 20% slope (1:5) on the upstream side. The design crest width is 25-feet wide, which would provide water depths of about 3.5 feet. Operational plans at the NSBL&D will be developed to ensure pool elevations are adjusted to pass high flows for elevations exceeding 115 ft (9,400 cfs) while minimizing velocities through the gates.

A submerged sheet pile wall is designed at a height of 3 to 4 feet above the river bottom or above the rock ramp. This wall guides the bottom-oriented SNS out of the deep river channel and through the ramp for downstream passage. Additionally, a small amount of dredging would be performed to shape the channel bottom so that the thalweg flows to the rock ramp. See **Table 8.1.2-2** for estimated construction quantities.

**Table 8.1.2-2: Off-Channel Rock Ramp Estimated Construction Quantities**

| Item                            | Quantity |
|---------------------------------|----------|
| Mobilization/Demobilization     | 1        |
| Armor Stone(tons)               | 88,000   |
| Bedding Stone(tons)             | 20,000   |
| Weir Stone 10% of armor         | 8,800    |
| Clearing and Grubbing(acres)    | 18       |
| Gate Replacement (each)         | 2        |
| Sheet Pile Wall (lf)            | 1,300    |
| Excavation(c.y.)                | 275,000  |
| Access Road Construction (c.y.) | 15,000   |

This design requires the least modification to the existing dam of the alternatives considered by the District. None of the gates would need to be removed from the dam; however, the two end gates would need to be modified. The present ability of the Lock & Dam project to reduce flood levels in upstream areas would be retained. The dam itself would not require modification. The lock and its operation would be unaffected. The Off-Channel Rock Ramp would reduce the work that would need to be performed if funds become available to rehabilitate the Lock & Dam. The rock ramp would remove the requirement to construct a fish passage structure, since it would provide the same function which would reduce the cost of the rehabilitation project. The dam would still need to be rehabilitated, to stabilize its structure and ensure its function continues to be provided in the future. The lock and its control house would still require the same amount of rehabilitation. Lands presently obtained for the Lock & Dam project would be needed to construct and operate the rock ramp around the South Carolina end of the dam. Those lands are presently wooded and are not used to operate the existing project. They provide structural stability to the dam and serve a limited security function. Those purposes would not be affected by construction and operation of the Off-Channel Rock Ramp. Additional lands would also need to be acquired to construct the rock ramp and for an access road to the site. Those lands would be acquired as part of the SHEP and not as part of the NSBL&D project. For details on additional real estate needs see Appendix B.

### 8.1.3 Marsh Restoration at Area 1S (Onslow Island)

Marsh restoration at Disposal Area 1S, also known as Onslow Island and owned by US Fish & Wildlife, is designed in such a way that tidal flow will be established across the entire restored site. The restoration design involves removing approximately 434,700 cubic yards of material to restore approximately 42 acres to an elevation suitable for growth of marsh vegetation (7.6 ft MLLW). See **Figure 8.1.3-1** for a plan view of this mitigation feature.

**Figure 8.1.3-1: Marsh Restoration at Area 1S**

Marsh restoration is broken into two pieces across the site. The northern area requires about 20,500 cubic yards of material to be removed. Clearing and grubbing for this area is approximately 8 acres. The southernmost area requires removal of about 405,000 cubic yards of material. Clearing and grubbing for this area is approximately 34 acres. A 4,360 ft long tidal conveyance feature will be constructed to provide tidal water exchange between Middle River and the restored marsh. This conveyance feature will require an additional 9,200 cy to be removed. If the excavated material is found to be suitable, it will be placed in the sediment basin to construct the broad berm. Unsuitable material will be pumped into Disposal Area 12A. **Table 8.1.3-1** summarizes the material quantities for this feature.

**Table 8.1.3-1: Material Quantities for Marsh Restoration at Area 1S**

| Feature                  | Material Quantity                                                     |
|--------------------------|-----------------------------------------------------------------------|
| Northern area            | 20,500 cy removed<br>8 acres clearing & grubbing                      |
| Southern area            | 405,000 cy removed<br>34 acres clearing & grubbing                    |
| Tidal Conveyance Feature | 9,200 cy removed<br>3 feet deep bottom width 10 ft<br>4,360 feet long |

#### 8.1.4 Hutchinson Island Boat Ramp

Due to the proposed closure of Rifle Cut as a mitigation feature to preserve freshwater marshes/wetlands, recreational boater access routes will be interrupted. For recreational boaters using the public access boat ramp at Houlihan Bridge on Front River, the route to move from this ramp to Back River will lengthen substantially with the closure of Rifle Cut. See **Figure 8.1.4-1**. To mitigate for this additional impact, a public access boat ramp on Hutchinson Island is proposed. This public access ramp would provide additional access to the Back River for recreational boaters.

The proposed boat ramp is located on government owned land at the tidewater on the North side of Hutchinson Island, adjacent to Back River. The proposed 2 lane concrete boat ramp will include the following: floating dock, 20 space trailer parking, handicap accessible and parking, and parking spaces for 12 single cars. See **Figure 8.1.4-2**. After construction of the public access ramp is complete, the property will be transferred to Chatham County, and the ramp will be their responsibility to operate and maintain.



Figure 8.1.4-1: Recreational Boating Routes

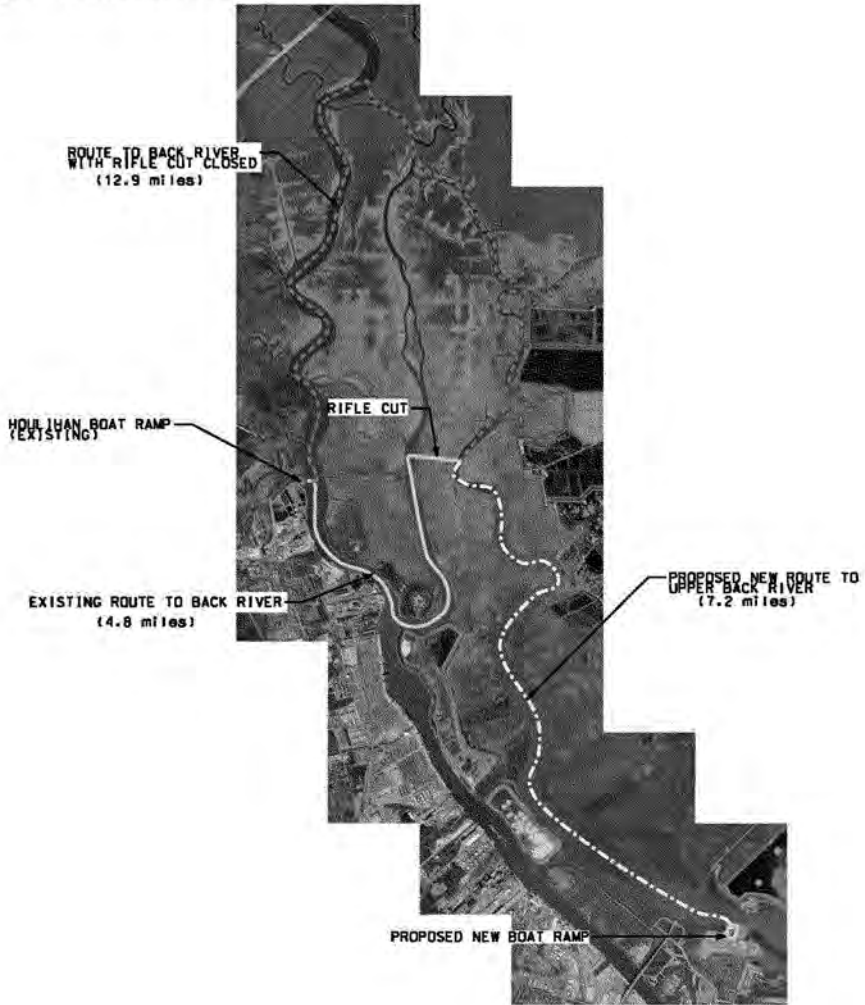




Figure 8.1.4-2: Hutchinson Island Boat Ramp



### 8.1.5 Dissolved Oxygen Injection System

To mitigate for D.O. impacts in the harbor resulting from SHEP, a plan has been developed to inject superoxygenated water into the estuary using Speece Cone technology. This plan was developed by Tetra Tech and results are documented in the report titled *Design of Dissolved Oxygen Improvement Systems in Savannah Harbor* which is included in the Engineering Investigations Supplemental Materials. The preliminary design of the oxygen injection system is also included in the Tetra Tech report. The design was completed under sub-contract by Eco-Oxygen Technologies, LLC.

The D.O. injection system will be land-based, with water being withdrawn from the river through pipes, then super-saturated with oxygen and returned to the river. The water intake structure would include screens to reduce the intake of trash and other suspended solids. The screens would be sized to keep flow velocities from exceeding 0.5 foot per second to minimize entrainment of fish larvae. The intake and discharge would be located along the side of the river and not extend out into the authorized navigation channel.

## 9.0 SHORELINE EFFECTS

### 9.1 SHIP FORCES ON THE SHORELINE

#### 9.1.1 Background

A study was conducted by the Coastal and Hydraulics Laboratory at the US Army Engineer Research and Development Center to determine the impacts of the proposed deepening on the adjacent shoreline. The 2007 report is entitled *Ship Forces on the Shoreline of the Savannah Harbor Project* and is included in the Engineering Investigations Supplemental Materials. This report was updated in July 2011 to more accurately represent the vessel fleet anticipated to be calling on the port of Savannah for the future with project condition and the future without project condition. The ship speed model and ship wave equation were updated using more recent guidance and input from the harbor pilots.

Ship forces having the potential to cause shoreline erosion were evaluated at the Savannah Harbor to compare the without project (existing) and the with-project (deepened) channels. Results of this study were used by the Savannah District in a separate study to evaluate shoreline erosion (see Section 9.2, Bank Erosion). An analysis of ship forces requires determination of comparable ship speeds in the without project (existing) and with project (deepened) channels. Field data were used to determine ship speed in the without project (existing) channel. An analytical model for ship speed, along with the assumption of equal ship operation including equal power setting in the without project and with project channels, was used to determine ship speed in the with-project channel.

#### 9.1.2 Report Updates

Based on updated sailing draft distribution and fleet forecast, the ship forces at the shoreline were reanalyzed in the report *2011 Reanalysis of Ship Forces at the Shoreline in Savannah Harbor (July 2011)* which is included in the Engineering Investigations Supplemental Materials. In the 2007 study, a typical/average draft and a large/design draft ship were used to evaluate ship forces. In this reanalysis, the typical ship compared in the existing and deepened channels is the 50th percentile or median ship draft from the sailing draft distributions. In this reanalysis, the large draft ship compared in the existing and deepened channels is the 95th percentile ship draft from the sailing draft distributions. Because distributions were not available for sub Panamax and their draft is not affected by deepening, the typical draft ship used was the average draft determined in the 2005 field study. The large draft Sub Panamax ship has draft equal to the design draft used in the 2007 study. In the 2007 study, a post Panamax ship having a beam of 140 ft was the design ship. In this reanalysis, the design ship has not changed but post Panamax beams have been refined to Generation 1 having average beams of 131.7 ft and Generation 2 having average beams of 142.9 ft.

Because of the changes in draft, ship speed had to be recomputed along with drawdown, return velocity, and wave height. In addition, the ship speed model and the ship wave equations were updated. Due to the updated draft information and improved ship speed and wave height models, all conclusions in the 2011 revised report supersede conclusions in the 2007 report.

### 9.1.3 Ship Operation and Speed Trends along Savannah Harbor

In the 2007 study, predicting ship speed in the deepened channel was based on existing speeds, change in ship draft, engine power setting, and increase in channel area. While those parameters are important in certain portions of the channel, there are three areas of the channel where ships must slow down to control their wake. Along the Savannah Harbor channel, ships must slow down at the Coast Guard, the LNG facility if a ship is docked, and beginning at Old Fort Jackson to the docks in Savannah. These three wake reduction areas affect a large portion of the channel because it takes significant channel distance for a ship to slow down and speed up. In these wake reduction areas, large ships must slow down more than small ships to result in the same wake effects. In these wake reduction areas, the requirement for safe wake has a far greater effect on ship speed than deepening of the channel.

### 9.1.4 Summary of the Revised Report

This reanalysis of ship forces addressed the following items:

- Updated draft information in the form of sailing draft distributions was used to define ship drafts to compare in the existing and deepened channels for each vessel class.
- The trends of speeds along the channel were identified and showed three wake reduction areas and 3 reaches where ships typically use full bell. The full bell is defined as the highest maneuvering setting with the highest speed a pilot can use and the one they prefer to use if conditions permit. This represents the most critical case for ship wake formation.
- Ship speeds were determined in the wake reduction areas based on maximum allowable drawdown to prevent moored ship effects.
- A revised ship speed model was developed and described. The model was validated against restricted channel data by Norrbín and shallow water effects on speed by Schlichting and Norrbín. Empirical coefficients were determined using Savannah Harbor ship event data collected in a 2005 field study.
- The ship speed model was used to determine ship speed in the three reaches where ships navigate at full bell. Drawdown and return velocity were determined in the reaches where full bell is used.
- Plots of speed along the entire Savannah Harbor channel were developed for each vessel class using the wake reduction speeds and the speeds in reaches using full bell.
- The 2007 ship wave model was revised, and a ship wave model by Kriebel and Seelig (2005) was obtained.
- Wave height was determined at the three wake reduction areas and the three full bell reaches for both existing and deepened channels using both the Kriebel and Seelig equations and the equation from the 2007 report that was revised in the reanalysis.
- Using forecasts of ship calls for existing and deepened channels, composite values of drawdown, return velocity, and wave height were determined that combine all ship classes into a single number for comparison.

- Drawdown and wave height were evaluated using total number of ships in each ship class and drawdown and wave height squared to reflect wave power.

### 9.1.5 Results and Conclusions

Evaluation of ship forces from drawdown, return velocity, and waves must be based on accurate ship speed because these effects vary based on the value used for speed, which is raised exponentially depending on which equation is used to predict ship force. Just as important as accurate speed prediction is consideration of operational constraints on ship speed. Ship pilots are responsible for the wake of their ship, and there are three areas along the Savannah Harbor channel where ship wake must be controlled. Because of the distance required to slow down and accelerate a ship, the wake reduction areas affect a significant length of the channel.

Long period drawdown is the best indicator of the effect of passing ships on moored vessels. Existing ships along the Savannah Harbor at wake reduction areas slow down such that their drawdown is about 0.7 ft or less. Ship speed in each wake reduction area was determined for each ship class and draft using the 0.7 ft drawdown limit.

The ship speed model used in the 2007 study was updated and a full description is provided in the reanalysis. In addition, the ship speed model was validated with independent restricted channel results from Norrbín and also compared to shallow water effects of Schlichting and Norrbín.

Previous studies have shown that ship pilots at Savannah Harbor and other channels will typically travel at full bell if not confronted by operational constraints such as wake reduction areas or Right Whale restrictions. The ship speed model was used to determine ship speeds at the three areas in Savannah Harbor where ships can travel at full bell.

Using speeds in the full bell reaches and the wake reduction areas, speed plots were presented for each ship class and both 50th percentile and 95th percentile drafts. The speed plots show that Sub Panamax ships, whose draft is not affected by channel deepening, will go faster in the deepened channel. Panamax ships, whose drafts increase by up to 1.5% in the deepened channel, will go slightly faster in the deepened channel where the cross sectional area increased by about 5%. Generation 1 post Panamax ships, whose drafts increase by about 11% in the deepened channel, will go slower in the deepened channel where the cross sectional area increased by about 5%. Generation 2 post Panamax ships, whose drafts increase by about 12-15% in the deepened channel, will go slower in the deepened channel where the cross sectional area increased by about 5%.

The ship wave model developed in the 2007 study was updated for the reanalysis and a second ship wave equation by Kriebel and Seelig (2005) was also used to predict ship wave heights.

Based on updated drafts, speeds along the channel, drawdown, return velocity, and wave height, ship forces have been recomputed and are described at various locations along the channel in the following paragraphs. From the viewpoint of changes in ship forces leading to changes in bank erosion, the three reaches where the ships are operating at full bell and thus highest speeds are the areas of primary concern.

At the full bell reach at Tybee Island, the presence of the south jetty and the 3500 ft distance from shoreline to navigation channel are significant factors in the magnitude and prediction of ship forces at the shoreline. Composite drawdown in the channel, return velocity in the channel, and wave height at the shoreline based on a single ship to represent all ship classes were less than or equal with the deepened channel when compared to the existing channel. Wave heights at Tybee Island shoreline from the Kriebel and Seelig equation are less in the deepened channel for all vessel classes and drafts. During the period of speed restrictions due the presence of Right Whales (Nov 15 to Apr 15), equal 10 knot speeds in existing and deepened channels will result in negligible secondary wave heights and lesser drawdown and return velocity in the deepened channel. Summing secondary wave power for all ships shows decreased wave power in the deepened channel from both wave equations.

Fort Pulaski was treated as a full bell location in the 2007 study. Based on this reanalysis and improved understanding of speeds along the Savannah Harbor channel, speeds at Fort Pulaski are strongly affected by the wake reduction area at the Coast Guard Docks. Fort Pulaski is in a location where speeds are dictated, not primarily by the power and size of the ship, but by the requirement of the pilot to control the ship's wake at the Coast Guard. In addition, during 6 months of the year, speeds are restricted by the Right Whale 10 knot limit. In the 2007 study conducted before the Right Whale speed restriction, Fort Pulaski was an analysis location where it was shown that wave power increased by up to 19% in the deepened channel. Wave height determined in this reanalysis using the Kriebel and Seelig wave height equation decreased for all ship classes and drafts in the deepened channel. Summing secondary wave power for all ships shows decreased wave power in the deepened channel from both wave equations.

At the full bell reach between Confined Disposal Facilities (CDFs) and Old Fort Jackson (OFJ), ships typically do not reach their maximum speed for full bell but do achieve speeds that are close to the full bell speed. Composite drawdown, return velocity, and wave height based on a single ship to represent all ship classes are up to 1.4% greater in the deepened channel. The 1.4% increase in composite wave height corresponds to a 3% increase in wave power. When considering total numbers of ships by summing wave power for all ship classes, wave power decreases in the deepened channel from both wave equations. When considering a relative measure of power using drawdown to represent transverse stern waves, sum of power from all ship classes is less in the deepened channel.

The full bell reach between the Coast Guard Docks (CG) and the Liquefied Natural Gas (LNG) dock is the only reach not restricted by operational constraints like the Coast Guard or Right Whale or limited channel length like the reach from the CDFs to OFJ. The CG to LNG reach has the highest magnitude of composite drawdown, return velocity, and wave height of all reaches. Composite values combining all ship classes of drawdown, return velocity, and wave height are less than or equal in the deepened channel when compared to the existing channel. When considering total numbers of ships by summing wave power for all ship classes, wave power decreases in the deepened channel from both wave equations. When considering a relative measure of power using drawdown to represent transverse stern waves, the sum of power from all ship classes is less in the deepened channel.

Summarizing, in the three reaches where the ships are operating at full bell and thus highest speeds, the reanalysis shows the sum of power from all ships to be less in the deepened channel than the existing channel; therefore, bank erosion due to ship wake should not be increased as a result of deepening the channel.

## 9.2 BANK EROSION

This analysis estimates the impacts to the shoreline (i.e. bank erosion) due to ship wakes as a direct result of SHEP deepening near City Front, the Bight Section, Fort Pulaski property and the northern beach of Tybee Island. The results of the bank erosion study are documented in two reports; 1) *Savannah Harbor Expansion Bank Erosion Study, Fort Pulaski and North Tybee Island, Georgia* and 2) *Savannah Harbor Expansion Bank Erosion Study Update*. Both are included in the Engineering Investigations Supplemental Materials. The evaluation is based on the difference between the ship wakes of today versus the ship wakes of the future, considering the without project condition compared with the deepened project condition. The total estimated shoreline erosion (due to all causes) is based on aerial photography from 1964 to 2003.

Analysis is based on the updated Fleet Forecast (June 2011) developed by the Economics team and included in the Economics Appendix (Appendix A), available soils information, bathymetry, topographic surveys, aerial photographs, historical information, observation/review of channel side slopes resulting from previous harbor widening and deepening projects, and information from previous dredging works regarding channel side slope performance. Direct correlations were made using the *Ship Forces on the Shoreline of the Savannah Harbor Project* report completed by USACE ERDC and the project fleet forecast.

The latest fleet forecast (June 2011) predicts the following fleet mix for the SHEP:

- For the year 2017: 4,285 calls or 8,570 passing events were counted for the existing 42 ft channel depth and 4,133 calls or 8,266 passing events were predicted (by estimation) for the 48 ft project depth alternative. This indicates a notable reduction of passing events that could contribute to bank erosion for Savannah Harbor.
- For the years 2030 and beyond: 7,204 calls or 14,408 passing events are predicted for the without project (42 ft) condition and 6,714 calls or 13,428 passing events are predicted for the 47 ft to 48 ft project depth alternatives. This represents about a 10% reduction of ship passing events which reduces erosion forces interacting with the banks of Savannah Harbor when compared to the without project condition.

The study concluded that the effects of deepening the navigation channel will not impact the City Front, the North Tybee Site, the confined disposal areas within the Bight Section, or the unprotected areas of Fort Pulaski with regard to erosion of bank materials at any location.

Unprotected portions of Fort Pulaski are subject to shoreline erosion measurable from 0.5 to 3.1 ft per year, depending on specific location. The majority of erosion is due to tide, flows, river mechanics, shape, and the present day ship traffic events. Future ship traffic without deepening is estimated to have a minimal to no measurable impact given the predicted fleet mix and volume. Zero additional erosion is predicted by forecast for any deepening increment or depth up to and including the 48 ft depth alternative.

Given the current traffic predictions and forecasts, no known or measureable bank erosion impacts are expected to be directly attributed to SHEP.



### 9.3 COASTAL EROSION

A study titled *Impacts of Savannah Harbor Expansion Project* was conducted jointly by the ERDC Coastal and Hydraulics Laboratory and the Charleston District (draft, October 2006) and is included in the Engineering Investigations Supplemental Materials. This study evaluated the impact of the proposed deepening of the Savannah Harbor navigation channel. A bathymetry and volume change analysis was conducted to provide the historical perspective of the Savannah nearshore evolution and to address review comments related to a previous ATM report (Applied Technology and Management, Inc. 2001, *Draft Savannah Harbor Beach Erosion Study: Savannah Harbor Expansion Project*). Numerical modeling of circulation, waves, and sediment transport was performed to compare pre- and post-deepening of the channel impacts on the coastal processes.

Deepening of the navigation channel, beginning in the 1870s, and subsequent construction of dual parallel jetties to stabilize the position of the navigation channel (1886-1897 time frame) are most likely the trigger for the changes in Tybee Island shoreline position that were observed between 1854/63 and 1900, and for the pattern of changes that has taken place since that time. There are no historical shoreline and bathymetric data available between 1854/63 and 1900 that would allow the details of that evolution, any variability in its rate of change during that time period, and a more direct linkage between navigation project construction and shoreline/morphology changes to be examined or discerned further. However, results of the historic shoreline analysis and volume change analysis, in addition to results from the circulation and GTRAN sediment transport models, provide a consistent picture of circulation and sediment transport processes at work. The following hypothesis is the most likely explanation for evolution of the inlet since construction of the navigation project.

Deepening of the navigation channel and construction of the dual parallel jetties appear to have concentrated the ebb tidal flow into a narrower, more concentrated, stronger ebb tidal jet. The navigation project also has fixed the location of the channel, as intended, as has construction of the submerged breakwater. Fixing the location of the channel reinforces the morphological response that occurs in response to the ebb and tidal currents that enter and flow through the channel. Concentration of the flow by the project produces higher ebb currents within the jet. Prior to project construction, ebb velocities in this vicinity were probably weaker. Associated with enhanced ebb jet formation is increased gyre formation adjacent to the jet, i.e. on either side of the jet. This flow feature is observed at many structured inlets with high ebb currents. Enhanced gyre formation produces, at peak ebb within the channel, a return current on the flanks of the inlet that flows back toward the inlet entrance, in the same direction as that experienced during typical flood flow conditions. During the flood flow here, currents are directed toward the entrance throughout the ebb shoal region. Thus, a situation is created where currents adjacent to the channel are directed toward the entrance (in the flood flow direction) a much larger percentage of the time. The duration of flood flow is greater than the duration of ebb flow along the flanks of the inlet. The North Tybee Island Shelf is the southern flank of the inlet. This change in predominance of flow direction adjacent to the ebb jet is expected to produce a corresponding change in the sediment transport patterns and morphology in these same regions, compared to conditions that existed prior to deepening and jetty construction. These changes to the circulation and sediment transport patterns, created by the navigation project, are thought to explain the shoreline and morphologic changes that have occurred on Tybee Island, along with changes to sediment supply to the island from Barrett Shoals.

At present, the Tybee Island Shelf is in the flank of the jet and is influenced by the return flow of the gyre. The GTRAN results show that the sediment transport regime in the channel and immediately

adjacent to it are strongly ebb directed. The strong transport computed for the channel is consistent with the ebb dominance of this inlet system as evidenced by its massive ebb tidal delta. GTRAN results also show that a short distance away from the channel sediment, net sediment transport is directed toward the entrance, both north and south of the channel, albeit with much smaller transport rates than those computed in the channel. The GTRAN results also indicate that on the Tybee Island Shelf to the east of northern Tybee Island, sediment transport is directed toward the northwest in a net sense. This direction of transport suggests that the sediment from this region moves toward the North Tybee Shoal. The accumulation of sediment in the North Tybee Shoal (and associated migration of the South Channel to the north which has likely happened in response to the sediment accumulation there) and deflation of the Tybee Island Shelf are consistent with the results of the GTRAN model. It is likely that the sediment transport regime in this region has been altered compared to the regime that existed prior to construction of the navigation project, in response to changes in the circulation patterns and local dominance of ebb/flood flow. Additional simulations of the wave, circulation, and GTRAN models for an inlet configuration representing the pre-construction condition could shed additional light on the working hypothesis for the shoreline and beach evolution observed on north Tybee.

The GTRAN results reflect conditions in deeper water where waves tend to agitate and suspend sediment and currents tend to move the sediment, not the shallow surf zone region along the Tybee Island shoreline. The very shallow nearshore region is much more wave dominated than the offshore region for which GTRAN was applied. Shoreline change modeling to examine this inner surf zone region was not part of the scope of this effort, but the minor changes in the nearshore wave results indicate that the deepening will have little impact on the shoreline. The historical shoreline change analysis showed the presence of a nodal zone around 2<sup>nd</sup> Street, north of which sand appears to be transported to the north by wave action, and south of which sand appears to be transported to the south. The hot-spot is in the region of the nodal zone, a divergent zone in which sediment tends to leave the region in both directions, in a net sense. The erosion within this nodal zone along north Tybee, is likely to be caused both by the ebb tidal deflation that occurs offshore as well as the gradients in alongshore transport created by the wave-dominated transport in the very nearshore zone.

Another possible factor in the evolution of the north half of Tybee Island is the unusually frequent and severe tropical storm activity during the period from 1879 to 1899. This increase in storm activity could have exacerbated the situation created by initial project construction and produced unusually high rates of sediment transport and morphology change. However, it seems unlikely that a single extreme event, or sequence of hurricane/tropical storm events in the region alone are capable of stimulating the shoreline and offshore morphology changes that have occurred on Tybee Island and in the Tybee Island Shelf. The GTRAN sediment modeling results indicate that the sediment transport regime during a single episodic event, like Hugo (which was re-tracked to have a much larger impact on the area than it actually had), is similar to the pattern seen for non-hurricane conditions but is greater in magnitude in some locations (not all) than any of the months of normal winter storm activity that were examined. But where the magnitude was greater, the increase is only a factor of 1 to 5 greater. For this magnitude of difference, and in light of the infrequency and short duration of episodic events, the more typical month-to-month forcing in response to an increasingly deeper channel and tighter ebb tidal jet appears to be a more likely trigger for the shoreline and beach evolution that has taken place.

GTRAN results show that the net sediment movement on the southern half of the Tybee Island Shelf is toward the west, i.e. toward the island. This computed result is consistent with the relative health of the southern half of Tybee Island, compared to the northern half. Historic shoreline changes showed



the southern half of the island to be accretionary for a significant time following construction of the project. Observations from other inlets suggest that as the ebb delta grows the down drift attachment bar migrates to the south. The attachment bar is the location on the ebb delta where sand moving around the ebb delta, from updrift to downdrift in a net sense, feeds the nearshore zone of the downdrift beach. This process may also be occurring at Tybee Island, and at present, the feeding appears to be occurring at the southern half of the island. Some of the sediment eroded from the bulge in shoreline (present in 1854/1863, but not in 1900) appears to have moved south and accreted on the southern half of the island following project construction. The shoreline position of south Tybee prior to beach fill placement was well seaward of its position prior to construction of the navigation project. The current navigation channel appears to be a nearly complete sink for any sediment moving from north to south along the shelf (suggested by pre- and post-dredging surveys and the consistency of dredging volumes following deepenings). Placement of dredged material back into the nearshore zone of Tybee Island would be a means for restoring this supply of sand to the Tybee beach system.

The circulation and wave modeling indicate very small changes associated with the proposed deepening. The GTRAN results provide insight about what this deepening will do in terms of sediment transport regime, which is expected to be similar to that of past deepenings. GTRAN results for the existing condition and the with-deepened-channel condition indicate that the additional channel deepening will not change the general overall pattern of sediment transport in the region. The most noticeable changes were computed in the channel.

Transport in the Tybee Knoll Bar Channel reach showed decreases in magnitude for all four of the typical months of simulation, but conditions remain strongly ebb-dominant. The magnitude of change was greatest here (15-20 percent), compared to changes throughout the rest of the system (changes elsewhere were generally quite small, several percent). Some small increases to shoaling rates in this sector of the channel might be expected in light of these decreases, but gradients in transport (which dictate accumulation rates) do not appear to be altered very much. For the extreme hurricane event (expected to be a very rare event), conditions remain ebb dominant and transport rates increase (factor of 2 greater) rather than decrease as they do for the other four months.

Transport in the Tybee Roads Channel reach consistently shows increases for each of the typical months, but only very slight increases of a few percent. No significant changes in sedimentation are expected in this reach of the navigation channel. Transport rates increase in this portion of the channel for the re-tracked Hugo event (about a factor of 2 or greater), as they do for all sections of the main channel. Transport remains strongly ebb dominant in this reach.

In the Tybee Range Channel reach, the outer limits of the navigation channel, changes in transport rate are also very small. The deepening increases rates for one month, shows zero change for one, and shows slight decreases for two of the months. All increases or decreases are small (a few percent). For re-tracked Hugo, the deepening only increases transport by about 20%, compared to a factor of 2 in the other channel reaches. This section of channel remains ebb-dominant. These changes do not suggest any significant changes in channel shoaling, and they suggest that the channel region will remain strongly ebb-dominant in terms of sediment transport direction.

Average transport within the Tybee Island Shelf region consistently shows slight increases or no change for each of the four typical months and an increase for the extreme event. No decreases were computed. Patterns appear unchanged, and the net direction of movement appears to remain to the northwest. Slight increases suggest a tendency for sediment to be transported from the shelf region to

the northwest at a higher rate. This would be consistent with the hypothesized model for how sand has been moving to the northwest in response to initial project construction and subsequent deepening. This proposed deepening seems to produce a result consistent with that hypothesis. However, the magnitudes of change are quite small, in the range from 0 to 2 percent for all months and even for the extreme hurricane event. Zero change was computed for two of the four months. Computations show that channel deepening will have negligible effect on the Tybee Island Shelf.

For North Tybee Shoal region, computations show a consistent decrease in transport rate for all four months, about 5 percent or less; however, for the extreme hurricane event, transport rates are increased by about 40%. These changes suggest that sediment being transported into the north Tybee shoal region will have less tendency to leave the region, but this is more dictated by changes to the transport gradients. Such a trend would be consistent with historic accumulation of sediment in these shoals.

## 10.0 SEDIMENTATION ANALYSIS

A study was conducted to determine the effects of SHEP regarding sedimentation rates, volumes, and patterns. The results, which are summarized here, are documented in full in the report titled *Sedimentation Analysis* which is included in the Engineering Investigations Supplemental Materials. In the evaluation, the effects of past dredging and construction activities were analyzed to gain an understanding of how sedimentation in the navigation channel responds to changes. Understanding how the system responded to past changes was used as the basis to make predictions on sediment volume and shoaling rates and patterns with the proposed project.

### 10.1 SEDIMENT SOURCES & TYPE

The major sources of sediment to Savannah Harbor are: 1) sediments suspended in the freshwater flows carried downstream by the river and 2) the offshore sediments carried into the harbor by tidal currents. Current velocities and the location of the mixing zone between fresh and salt water influence the distribution of the shoaling from these two sources.

Results of an analysis of a suspended sediment sample taken at Clyo, Georgia, located approximately 65 miles above the mouth of the Savannah River, indicate that sediment supplied by the river and deposited throughout the inner harbor is primarily fine silt and clay. The bed load material transported by the river is deposited in the extreme upper reaches of the Savannah Harbor above Station 103+000. The shoal materials in these reaches are principally sand and account for no more than 5 % of the total volume material dredged from the harbor.

Grain size distributions for the inner harbor and entrance channel are shown in **Table 10.1-1** and graphically in **Figures 10.1-1** and **10.1-2**. The inner harbor sediments are primarily silts and clays between Stations 103+000 and 56+000. The reach between Stations 56+000 and 25+000 is a transition reach that has a higher percentage of sand in its distributions than the sediment distributions of the upstream reach. A notable exception is in the vicinity of Station 36+000, which has a high percentage of silt and clay and almost no sand. This location is near the confluence of the inner harbor channel with both Elba Island and Fields Cuts (Atlantic Intracoastal Waterway crossing). The lower harbor channel sediment distributions between Stations 25+000 and 0+000 are primarily sand, which indicates that the source of sediment for this reach is offshore. The entrance channel sediments are primarily sand with exceptions between the jetties and at Station -45+000(B), which have large silt and clay components. The upstream source of sediment for the upper river reaches and the ocean source for the lower river reach are consistent with the observation that essentially all of the shoaling material from upstream sources is being trapped within the system.

**Table 10.1-1: Grain Size Distribution**

| ID*   | Station | Channel        | % SAND | % SILT | % CLAY |
|-------|---------|----------------|--------|--------|--------|
| NB-13 | -45+000 | Entrance       | 8.7    | 66.8   | 24.5   |
| NB-12 | -35+000 | Entrance       | 83.9   | 0      | 16.1   |
| NB-11 | -25+000 | Entrance       | 78.2   | 5.8    | 15.8   |
| NB-10 | -15+000 | Entrance       | 67.1   | 12.3   | 20     |
| NB-9  | -5+000  | Entrance       | 30.8   | 53     | 16     |
| IH-8  | 5+250   | Inner          | 94.4   | 4.4    | 0.3    |
| IH-7  | 15+000  | Inner          | 88.2   | 2      | 9.1    |
| IH-6  | 25+000  | Inner          | 93.7   | 0      | 2.5    |
| IH-5  | 35+000  | Inner          | 12.1   | 62.4   | 25.5   |
| SH-7  | 36+000  | Inner          | 0      | 65.3   | 34.7   |
| IH-4  | 44+000  | Inner          | 32.2   | 32.3   | 35     |
| IH-3  | 55+750  | Inner          | 27.2   | 45.5   | 27     |
| SH-6  | 56+000  | Inner          | 10.6   | 75.7   | 13.7   |
| SH-5  | 61+500  | Inner          | 13.4   | 53.5   | 33.1   |
| IH-2  | 64+000  | Inner          | 2.7    | 59.8   | 37.5   |
| SH-4  | 67+250  | Inner          | 78.4   | 13.5   | 8.1    |
| IH-1  | 75+000  | Inner          | 5.7    | 49.8   | 44.5   |
| SH-3  | 90+000  | Inner          | 9.6    | 55.6   | 34.6   |
| SH-1  | 99+000  | Inner          | 14.4   | 54     | 31.6   |
| SH-8  | 2+750   | Sediment Basin | 17.5   | 49.4   | 33.1   |
| SH-9  | 5+250   | Sediment Basin | 0      | 72.8   | 27.2   |
| SH-10 | 8+000   | Sediment Basin | 0      | 66.9   | 33.1   |
| SH-11 | 10+500  | Sediment Basin | 17.6   | 46.2   | 36.2   |

\*See **Figure 10.1-1** and **10.1-2** for ID locations.

Figure 10.1-1: Grain Size Distribution Station 90+000 to 5+000

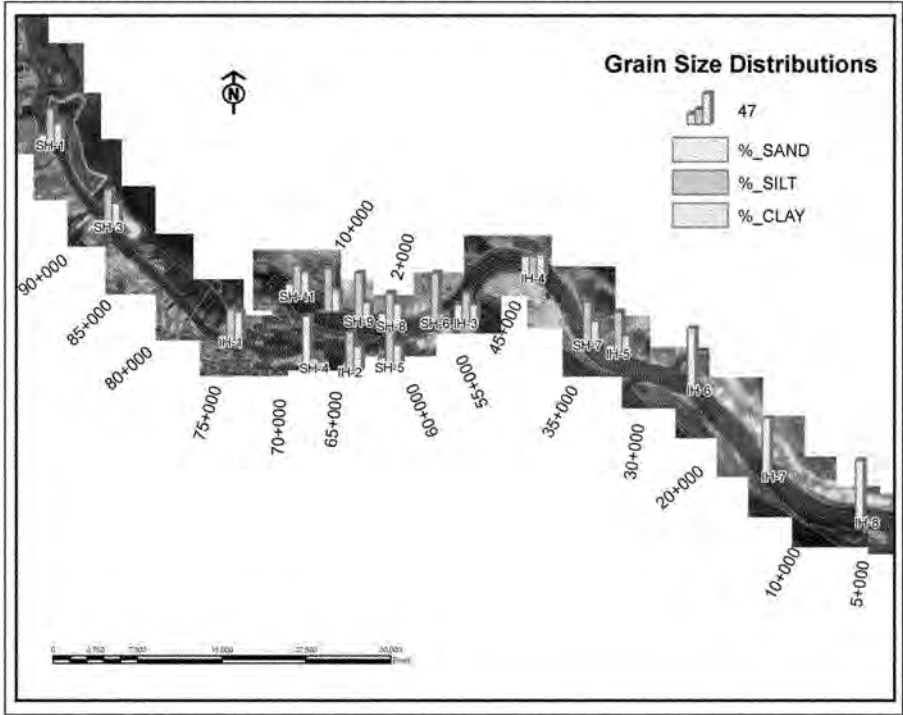
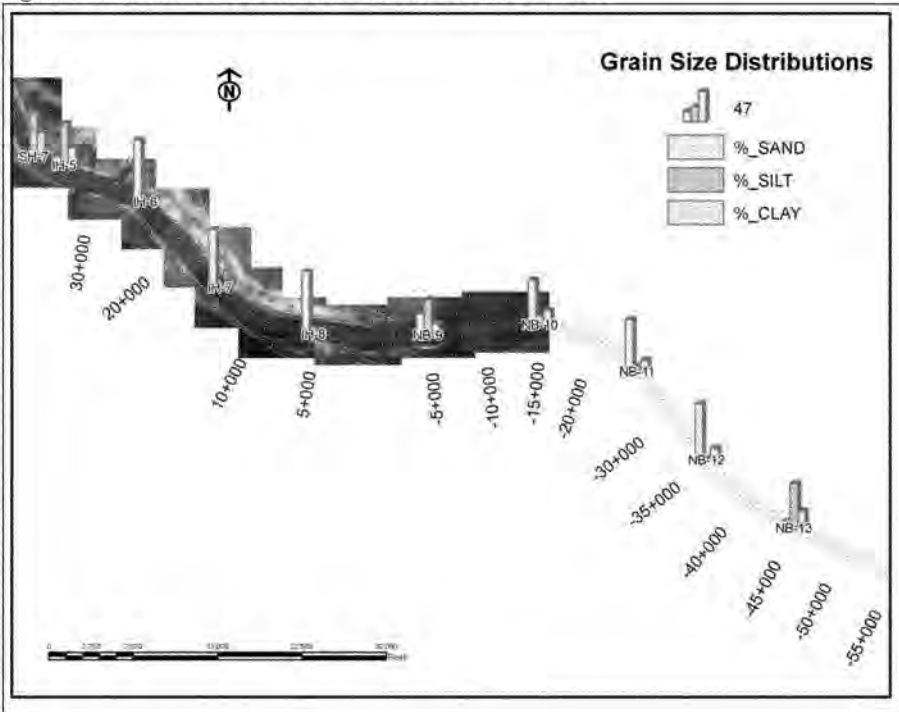


Figure 10.1-2: Grain Size Distribution Station 30+000 to -55+000



## 10.2 THE SHOALING PROCESS

Past channel deepenings have modified the estuary's tidal conveyance to the point where the full tidal prism reaches the upstream of the harbor. Analysis shows that the last channel deepening did not change the shoaling volume or distribution, indicating that the channel already captures all of the sediment that enters the harbor. The shoaling patterns of these sediments are outlined in the following paragraphs.

In the middle harbor reach, Stations 28+000 to 67+000, and upper harbor reach, Stations 67+000 to 103+000, silts and clays form low-density shoals in areas with low velocities or eddies. Areas with low velocities have low bottom shear stresses which allow deposition and the circular flow of the eddies promote flocculation and trap sediment. Salinity affected currents cause a flow converging area at the location of zero net bottom flow, which becomes an area of high shoaling. The salinity effects also cause the bottom flows in the lower harbor to have a net upstream flow, which traps ocean derived sand.

The source of shoaling material in the upper and middle reaches of the harbor is silt and clay eroded by rain runoff in the piedmont. The clay particles have a negative charge and a diffuse layer of positive

ions surrounds the particle. The diffuse layer that surrounds the clay particles makes them mutually repulsive. The individual clay particles have an extremely slow settling rate, which allows them to travel hundreds of miles downstream from the piedmont to the estuary. The saline water of the estuary has a high ionic concentration, which compacts the diffuse layer and allows the particles to come closer together. When the particles enter a mixing flow they collide and the attractive forces, which exist between all colloidal particles, enables the particles to form aggregates. The aggregates can become relatively large and settle rapidly. When the aggregates are carried to an area with weak currents, they form low-density shoals. The delicate structure of the aggregates and low density of the shoals make them responsive to the strength of the flow velocities. An area that has weak currents or eddies will be high shoaling area and an area of strong currents will be a low shoaling area. The nature of these low-density shoals can make volumetric analysis of shoaling patterns difficult. If a low-density shoal were disbursed and the aggregates broken up, new shoals that form from the shoal material could be denser or so thinly spread out that they are not recorded at all.

Savannah Harbor is in a partially mixed estuary in which the vertical mixing of salt and fresh water is not complete over the length of salt water intrusion. Surface salinities are appreciably less than the bottom salinities, and there is a large zone of mixing between fresh and salt water. Seaward of this mixing zone, the net bottom flow over a tidal cycle is upstream. Landward of this mixing zone, the net bottom flow is downstream. The converging bottom flows carries shoaling material to the location of no net bottom flow, which tends to be an area of high shoal volumes.

Shoaling in the Savannah inner harbor channels below Station 28+000 is due to sand carried into the channel from the ocean by the strong bottom flood currents. The shoal material in the lower harbor is almost entirely sand while the shoal material upstream of Station 28+000 is silt and clay. The sand is deposited during slack tide and the weaker bottom ebb currents cannot carry the sand back to the ocean source. Results from the prior physical model tests indicate that the bottom flood currents at Station 4+000 are a foot per second faster than the bottom ebb currents and that the net bottom flow in the lower portion of the harbor is upstream.

## 10.3 FINDINGS

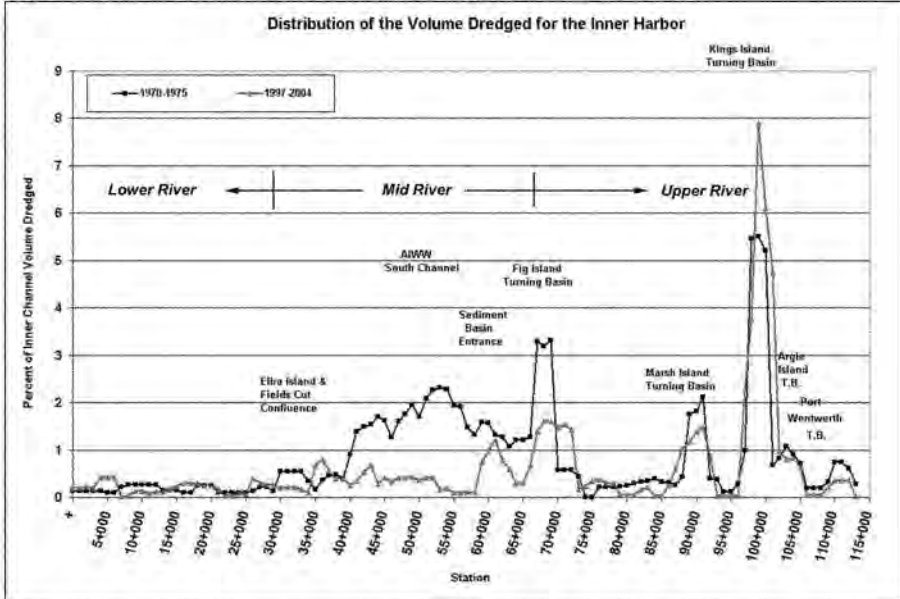
### 10.3.1 Shoaling Response to Inner Harbor Channel Depth Increases

To determine the changes to the amount and distribution of the inner harbor dredging volumes due to potential channel depth increases, the changes due to the 4-foot depth increase in 1994 were used as a predictor. In addition to the shoaling response to past changes, the velocities as predicted by the three-dimensional hydrodynamic model (EFDC) were used to check for potential shifts in shoaling distribution due to potential depth increases. No changes to the shoaling volume or distribution are predicted for the inner harbor due to depth increases.

Past Dredging Volumes as an Indicator – A comparison between the inner harbor dredging volume distributions between the periods 1970-1975 and 1997-2004 does not indicate any shoaling changes that can be attributed to a depth increase. There were multiple construction related changes between the two time periods, which subsequently affected O&M practices. However, the dredging and construction related changes reflected in the distributions are inner harbor depth increase from -38 ft to -42 ft between Stations 103+000 and 0+000, the widening of the channel from 400 ft to 500 ft between Stations 100+000 and 70+000, the enlargement of the Kings Island Turning Basin from 900 x 1,000 ft to 1,500 x 1,600 ft and the operation of the sediment basin. The tidegate and New Cut were not

operational during either the 1970-1975 or the 1997-2004 time periods. Despite changes in dredging related to these activities, there are no changes to the total volume dredged or to the shoaling distribution that can be attributed to the 1994 channel deepening and widening. See **Figure 10.3.1-1**.

**Figure 10.3.1-1: Distribution of the Volume Dredged for the Inner Harbor**

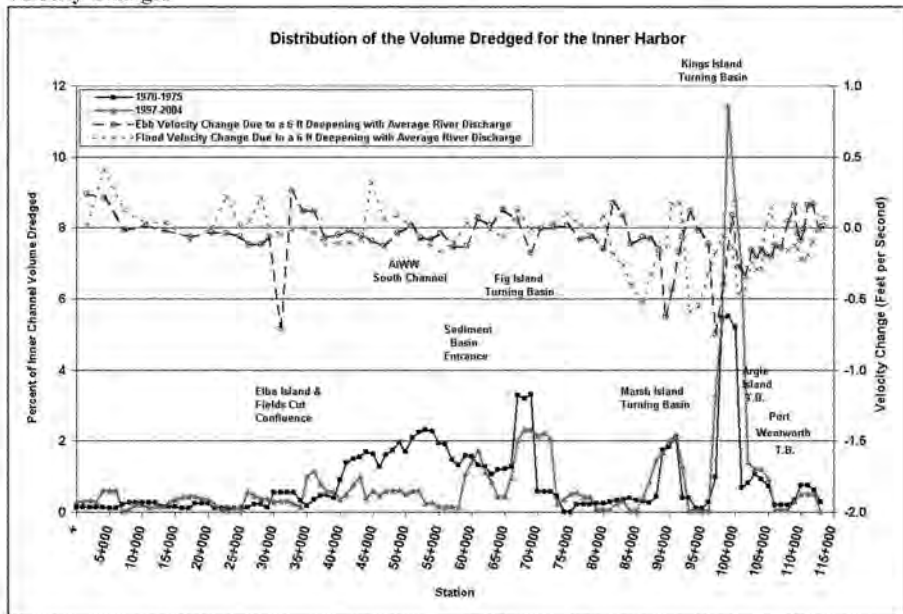


**Model Predicted Velocities as an Indicator** – To determine if proposed depth increases would change the shoaling pattern in the river, the EFDC model was run for low, average and high flow conditions with existing project depths, a 3-foot depth increase and a 6-foot depth increase. The low flow runs used historic river discharges starting on April 1, 1999 and ran for 214 days. The average flow runs used historic river discharges starting on August 1, 1997 and ran for 91 days. The high flow runs used historic river discharges starting on July 1, 1998.

There are specific locations where velocity changes occur as a result of the proposed deepening. The velocity changes due to a 6-foot deepening with average flow conditions best represents the locations where changes occur. Velocity changes are predicted at locations where there is high shoaling already occurring and no shift in shoaling pattern is predicted with two possible exceptions. See **Figure 10.3.1-2**. The first exception is a small shoal at Station 35+000. Based on the predicted ebb velocity changes, this shoal may shift toward Station 31+000. The second exception is the spreading out of the Marsh Island turning basin shoal based on predicted flood velocity changes. If these exceptions did occur, they would cause small changes in the shoaling distribution, but the response of the volume-dredged distribution to the last deepening in 1994 indicates that these changes will not occur.



**Figure 10.3.1-2: Distribution of the Volume Dredged for the Inner Harbor with Model Predicted Velocity Changes**



**Tidal Range as an Indicator** – Another indication that there will not be major flow induced changes due to potential channel deepening is that the past depth increases have improved the conveyance of the channel to the point where a full tidal range is presently moving up the channel to the upstream end of the harbor. The mean tidal range at the entrance to Savannah Harbor, Fort Pulaski, is 6.9 ft and the mean tidal range at the upstream end of the harbor is 7.0 ft at Port Wentworth. Additional deepening would not significantly affect the tidal flow or salinity related shoaling that is associated with the location of no net bottom flow.

Since 1) there were no changes to the shoaling volume or distribution attributed to the last channel deepening, 2) the channel already captures essentially all of the sediment that enters the harbor, and 3) the future depth increases will extend along the existing channel side slopes which will decrease the bottom width of the channel, no major change to the shoaling volume or distribution is predicted. The one small exception is the meeting area extending into an existing shoal upstream of the sediment basin entrance.

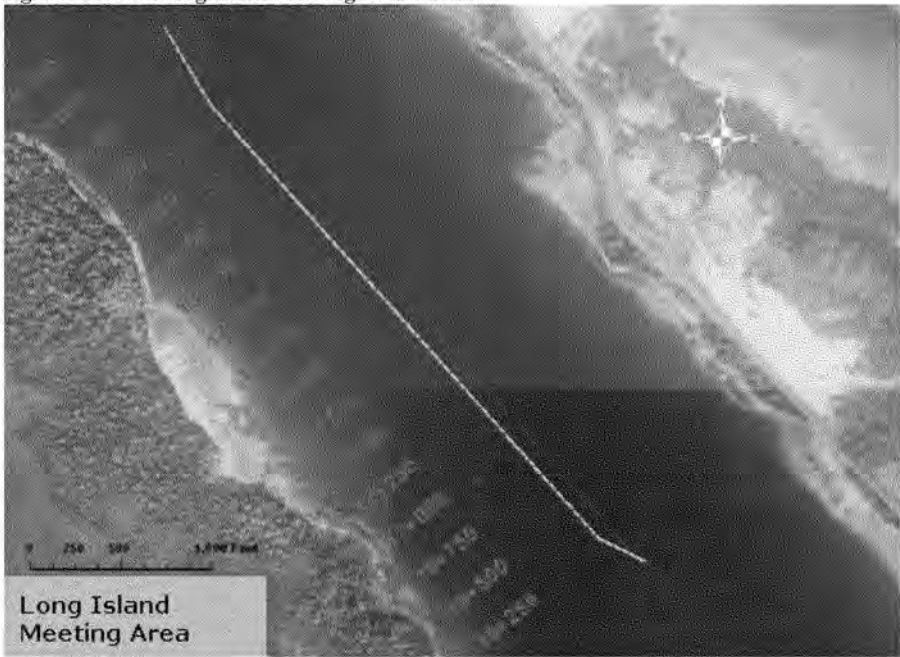
### 10.3.2 Shoaling Response to Meeting Areas

In addition to deepening, two meeting areas are included in the project design. **Figures 10.3.2-1 and 10.3.2-2** show the location of the Oglethorpe and Long Island meeting areas. In these areas, shoaling is anticipated to shift from the adjacent channel into the meeting area, particularly in the Oglethorpe

meeting area where a large amount of material currently shoaling in the Sediment Basin is predicted to move.

**Figure 10.3.2-1: Oglethorpe Meeting Area Location**



**Figure 10.3.2-2: Long Island Meeting Area Location**

### 10.3.3 Shoaling Response to Mitigation Features

Features of mitigation Plan 6a were evaluated for sedimentation impacts were evaluated from two perspectives 1) the shoaling effects resulting from the discontinued use of the sediment basin as an O&M feature and 2) the overall salinity regime changes in Front River associated with implementing all of the mitigation features included in Plan 6a.

#### 10.3.3.1 Discontinued Use of the Sediment Basin

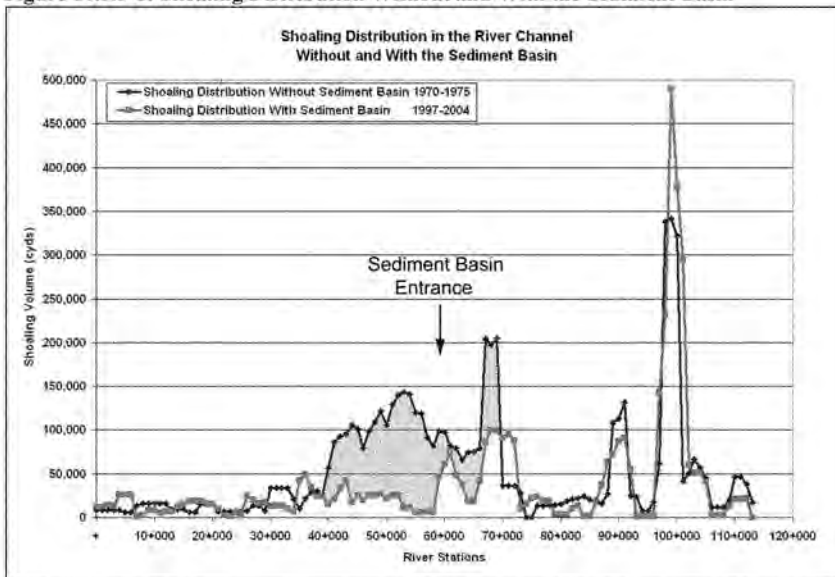
The sediment basin is an O&M feature, located at the mouth of Back River, which allows for cost effective dredging maintenance of the channel. Details of this feature regarding O&M practices are outlined in Section 3. With regards to sedimentation and shoaling, an examination of sediment basin efficiency both currently and with the proposed channel depth increases was evaluated for this project and are documented in the report titled *Sedimentation Analysis* which is included in the Engineering Investigations Supplemental Materials.

Despite the sediment basin's usefulness as an O&M feature, discontinuing its use is part of the proposed mitigation plan. The sediment basin currently acts as a trap for sediments but also traps salinity which, due to the depths in the basin, can more readily move upstream through the tidegate into the Back River system. This is especially true during dry times when freshwater inflows coming

downstream are low. By discontinuing the use of the sediment basin as a maintenance feature and allowing it to fill naturally, the current upstream elevation on Back River could be extended through the sediment trap to the confluence with Front River. The modeling results show that filling the basin reduces salinity concentrations upstream in Back River by allowing more mixing and flushing of the area on each tidal cycle. Also, salinity concentrations are reduced by limiting the interaction between the Back River and the lowest portions of the water column on Front River that have the highest concentrations of salinity.

If the use of the sediment basin is discontinued, the sediment that is annually trapped in the sediment basin will begin to settle in the river channel in a pattern similar to that which occurred before the construction of the sediment basin. The river channel shoaling distributions, before and after construction of the sediment basin, are plotted in **Figure 10.3.3-1**. After construction of the sediment basin, the river channel shoaling volume between Stations 40+000 and 69+000 was reduced by 2,050,000 cubic yards. The 1,906,000 cubic yards that shoaled in the sediment basin, which is adjacent to the reach of river between Stations 40+000 to 69+000, was responsible for the majority of the shoaling reduction in the river channel. The remainder of shoaling reduction, between Stations 40+000 and 69+000, is accounted for in the enlarged turning basins upstream.

**Figure 10.3.3-1: Shoaling Distribution Without and With the Sediment Basin**



If the sediment basin is not maintained, the sediment that would have settled in the sediment basin will now be deposited in the river channel between Stations 40+000 and 69+000. The distribution is shown in **Table 10.3.3.1-1**.

**Table 10.3.3.1-1: Channel Shoaling Increases Due to Discontinued Use of the Sediment Basin**

| Station | Long Term Shoaling Average cy Existing Conditions | Long Term Shoaling Average cy Without Sediment Basin | Station | Long Term Shoaling Average cy Existing Conditions | Long Term Shoaling Average cy Without Sediment Basin |
|---------|---------------------------------------------------|------------------------------------------------------|---------|---------------------------------------------------|------------------------------------------------------|
| 0       | 11,866                                            | 11,866                                               | 38+000  | 24,392                                            | 24,392                                               |
| 1+000   | 11,866                                            | 11,866                                               | 39+000  | 24,867                                            | 24,867                                               |
| 2+000   | 13,946                                            | 13,946                                               | 40+000  | 15,157                                            | 50,776                                               |
| 3+000   | 12,266                                            | 12,266                                               | 41+000  | 21,054                                            | 78,654                                               |
| 4+000   | 25,921                                            | 25,921                                               | 42+000  | 32,835                                            | 79,121                                               |
| 5+000   | 25,921                                            | 25,921                                               | 43+000  | 42,262                                            | 77,469                                               |
| 6+000   | 26,184                                            | 26,184                                               | 44+000  | 17,155                                            | 100,139                                              |
| 7+000   | 1,026                                             | 1,026                                                | 45+000  | 25,345                                            | 91,506                                               |
| 8+000   | 2,445                                             | 2,445                                                | 46+000  | 20,211                                            | 71,338                                               |
| 9+000   | 8,337                                             | 8,337                                                | 47+000  | 25,524                                            | 89,525                                               |
| 10+000  | 8,160                                             | 8,160                                                | 48+000  | 25,158                                            | 99,451                                               |
| 11+000  | 5,337                                             | 5,337                                                | 49+000  | 26,665                                            | 111,788                                              |
| 12+000  | 6,781                                             | 6,781                                                | 50+000  | 22,060                                            | 97,610                                               |
| 13+000  | 6,888                                             | 6,888                                                | 51+000  | 25,242                                            | 120,877                                              |
| 14+000  | 11,533                                            | 11,533                                               | 52+000  | 25,242                                            | 131,767                                              |
| 15+000  | 14,790                                            | 14,790                                               | 53+000  | 10,667                                            | 142,640                                              |
| 16+000  | 18,308                                            | 18,308                                               | 54+000  | 11,369                                            | 139,781                                              |
| 17+000  | 18,756                                            | 18,756                                               | 55+000  | 6,245                                             | 119,986                                              |
| 18+000  | 18,764                                            | 18,764                                               | 56+000  | 5,751                                             | 119,605                                              |
| 19+000  | 15,669                                            | 15,669                                               | 57+000  | 6,683                                             | 90,569                                               |
| 20+000  | 15,186                                            | 15,186                                               | 58+000  | 6,011                                             | 81,041                                               |
| 21+000  | 9,740                                             | 9,740                                                | 59+000  | 46,565                                            | 79,048                                               |
| 22+000  | 2,516                                             | 2,516                                                | 60+000  | 60,347                                            | 70,804                                               |
| 23+000  | 1,858                                             | 1,858                                                | 61+000  | 74,865                                            | 74,865                                               |
| 24+000  | 6,023                                             | 6,023                                                | 62+000  | 47,994                                            | 57,927                                               |
| 25+000  | 4,572                                             | 4,572                                                | 63+000  | 37,084                                            | 49,992                                               |
| 26+000  | 24,413                                            | 24,413                                               | 64+000  | 18,925                                            | 67,354                                               |
| 27+000  | 19,840                                            | 19,840                                               | 65+000  | 18,679                                            | 68,045                                               |
| 28+000  | 16,054                                            | 16,054                                               | 66+000  | 42,012                                            | 60,960                                               |
| 29+000  | 16,521                                            | 16,521                                               | 67+000  | 85,725                                            | 168,061                                              |
| 30+000  | 12,758                                            | 12,758                                               | 68+000  | 99,524                                            | 154,911                                              |
| 31+000  | 13,158                                            | 13,158                                               | 69+000  | 99,524                                            | 162,270                                              |
| 32+000  | 13,158                                            | 13,158                                               | 70+000  | 91,460                                            | 91,460                                               |
| 33+000  | 10,511                                            | 10,511                                               | 71+000  | 95,409                                            | 95,409                                               |
| 34+000  | 6,595                                             | 6,595                                                | 72+000  | 87,680                                            | 87,680                                               |
| 35+000  | 42,128                                            | 42,128                                               | 73+000  | 9,810                                             | 9,810                                                |
| 36+000  | 49,315                                            | 49,315                                               | 74+000  | 14,794                                            | 14,794                                               |
| 37+000  | 34,386                                            | 34,386                                               | 75+000  | 21,570                                            | 21,570                                               |

**Table 10.3.3.1-1: Channel Shoaling Increases Due to Discontinued Use of the Sediment Basin  
(continued)**

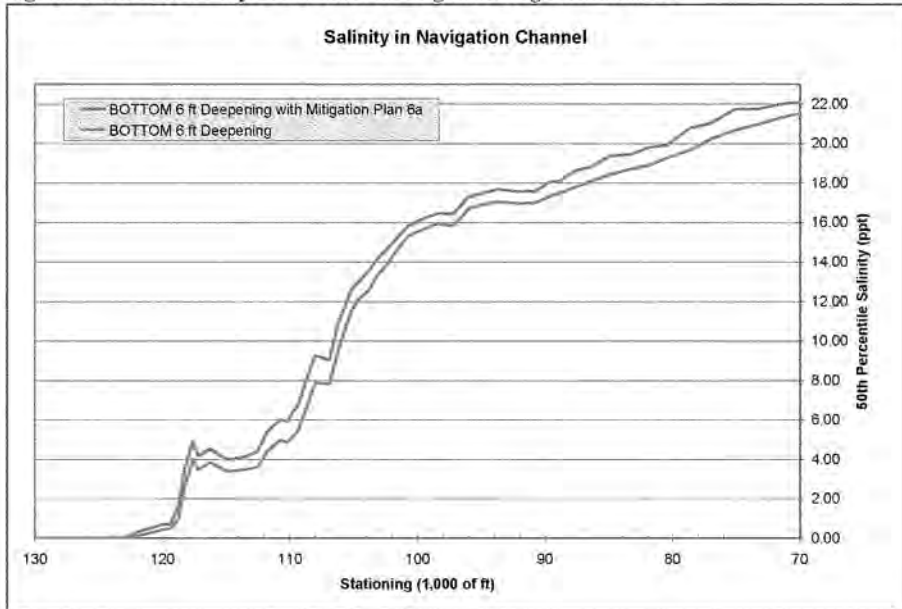
| <b>Station</b> | <b>Long Term<br/>Shoaling<br/>Average cy<br/>Existing Conditions</b> | <b>Long Term<br/>Shoaling<br/>Average cy<br/>Without<br/>Sediment Basin</b> |
|----------------|----------------------------------------------------------------------|-----------------------------------------------------------------------------|
| 76+000         | 23,825                                                               | 23,825                                                                      |
| 77+000         | 18,418                                                               | 18,418                                                                      |
| 78+000         | 18,418                                                               | 18,418                                                                      |
| 79+000         | 3,746                                                                | 3,746                                                                       |
| 80+000         | 2,959                                                                | 2,959                                                                       |
| 81+000         | 2,959                                                                | 2,959                                                                       |
| 82+000         | 9,995                                                                | 9,995                                                                       |
| 83+000         | 13,606                                                               | 13,606                                                                      |
| 84+000         | 1,586                                                                | 1,586                                                                       |
| 85+000         | 1,586                                                                | 1,586                                                                       |
| 86+000         | 16,780                                                               | 16,780                                                                      |
| 87+000         | 36,899                                                               | 36,899                                                                      |
| 88+000         | 63,586                                                               | 63,586                                                                      |
| 89+000         | 72,272                                                               | 72,272                                                                      |
| 90+000         | 86,497                                                               | 86,497                                                                      |
| 91+000         | 91,420                                                               | 91,420                                                                      |
| 92+000         | 54,434                                                               | 54,434                                                                      |
| 93+000         | 2,050                                                                | 2,050                                                                       |
| 94+000         | 2,050                                                                | 2,050                                                                       |
| 95+000         | 2,050                                                                | 2,050                                                                       |
| 96+000         | 1,693                                                                | 1,693                                                                       |
| 97+000         | 142,429                                                              | 142,429                                                                     |
| 98+000         | 232,556                                                              | 232,556                                                                     |
| 99+000         | 489,662                                                              | 489,662                                                                     |
| 100+000        | 378,601                                                              | 378,601                                                                     |
| 101+000        | 293,983                                                              | 293,983                                                                     |
| 102+000        | 60,257                                                               | 60,257                                                                      |
| 103+000        | 50,618                                                               | 50,618                                                                      |
| 104+000        | 51,599                                                               | 51,599                                                                      |
| 105+000        | 40,057                                                               | 40,057                                                                      |
| 106+000        | 2,684                                                                | 2,684                                                                       |
| 107+000        | 2,684                                                                | 2,684                                                                       |
| 108+000        | 2,684                                                                | 2,684                                                                       |
| 109+000        | 13,305                                                               | 13,305                                                                      |
| 110+000        | 21,336                                                               | 21,336                                                                      |
| 111+000        | 21,336                                                               | 21,336                                                                      |
| 112+000        | 22,334                                                               | 22,334                                                                      |

### 10.3.3.2 Implementation of Mitigation Plan 6a

To predict if there will be a shift of the shoaling distribution due to the implementation of Plan 6a, the numerically modeled shift of the salinity distribution associated with the implementation of the mitigation Plan 6a was compared to the measured shift of the salinity distribution and the corresponding shoaling shift in a physical modeled of a deepened Savannah River. The use of a shift in the salinity distribution as an indicator of a shift in the shoaling distribution is valid since not only is the shoaling process sensitive to salinity concentrations, but the hydrodynamics that affect the shoaling distribution also affect the salinity concentration.

The salinity distributions, as predicted by the three-dimensional hydrodynamic model (EFDC), are shown in **Figure 10.3.3.2-1** for the 6ft deepening with and without Plan 6a. The average shift in the 10 ppt concentration is on the order of 500 ft. The predicted salinity shift is much less than the physical model salinity shift which did not produce a significant change in the shoaling distribution. Based on the small predicted change in the salinity distribution for Plan 6a, implementation of Plan 6a will not change the shoaling distribution from the 6 ft deepening. The predicted salinity changes for the other deepening alternatives are less than what is represented in **Figure 10.3.3.2-1**; therefore, they also will not affect the without mitigation shoaling distribution.

**Figure 10.3.3.2-1: Salinity Distributions Along the Navigation Channel**



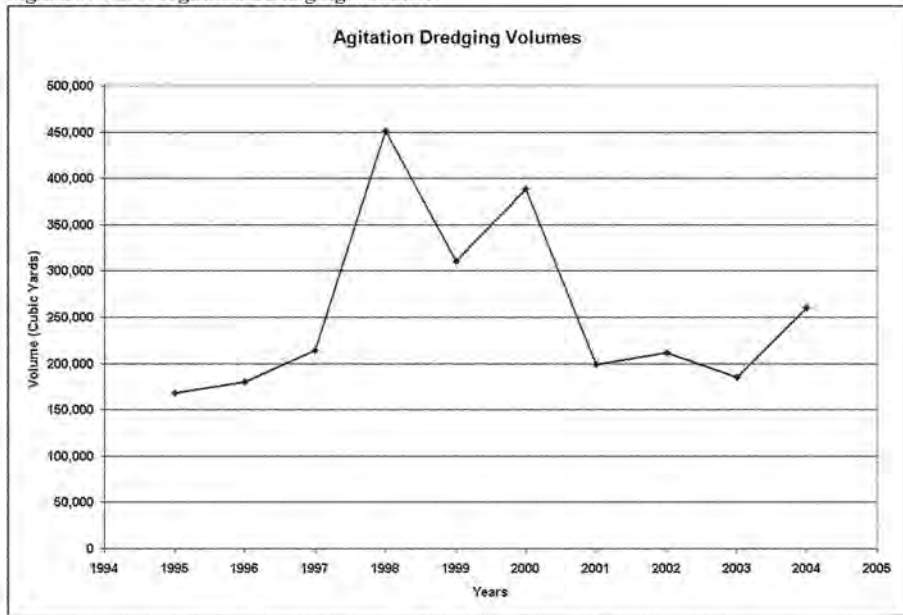
### 10.3.4 Shoaling Response and Berth Maintenance

The berths in Savannah Harbor are maintained by agitation dredging. **Table 10.3.4-1** lists the agitation dredging permit holders and their approximate location. Records of the agitation volumes go back to 1995. The total volume removed by agitation is plotted in **Figure 10.3.4-1** for the period 1995 to 2004. While the existing shoaling pattern is not predicted to change with project depth increase, the mitigation plan will cause a shift in shoaling in the harbor. By allowing the sediment basin to fill, the material that would have settled in the basin will now be deposited in the river channel between Stations 40+000 and 69+000. Berths falling within this area may experience an increase in shoaling. However, it is expected that the shoaling will be concentrated in the deeper channel adjacent to the berths.

**Table 10.3.4-1: Agitation Dredging Permit Holders**

| Permit Holders               | Approximate Channel Station |
|------------------------------|-----------------------------|
| S.T. Services                | 60+500                      |
| Conoco Phillips              | 61+000                      |
| S.T. Services Dock 2         | 62+300                      |
| G P Gypsum                   | 63+600                      |
| East Coast Term.             | 68+450                      |
| Ga. Ports Auth. O.T.         | 78+000-82+000               |
| Colonial Oil (Plant 1)       | 83 + 424                    |
| Gobal Ship Systems           | 84+000                      |
| Colonial Oil (Plant 2)       | 85 + 594                    |
| International Paper          | 88+500                      |
| Citgo                        | 90+000                      |
| Colonial Ga. Kaolin          | 91+000                      |
| Conbulk Mar. Term. (S. Bulk) | 91+872                      |
| Ga. Ports Auth. G.C.         | 92+000-102+000              |
| Savannah Sugar               | 104+100                     |
| G.P.A. Berth 7               | 109+000                     |



**Figure 10.3.4-1: Agitation Dredging Volumes**

### 10.3.5 Shoaling Response to Entrance Channel Depth and Length Increases

At the present project depth of 44 ft, the entrance channel is a sediment sink, which is a total interdiction of the littoral transport. Increases in depth will not increase the channel's ability to capture sediment. The average annual shoaling volume record did show an apparent increase in shoaling after the last deepening, but this was due to the short post-deepening record not including both a high and low shoaling period as did the pre-deepening record. A small volume increase is predicted based on an increase in channel length.

The entrance channel is presently 42 ft deep and 500 ft wide from Station 0+000 to -14+000. See **Figure 10.3.5-1**. From Station -14+000 to -60+000, the channel is 44 ft deep and 600 ft wide. The entrance channel is a trap for all of the sediment that is transported to it. To substantiate that the entrance channel is a sediment sink, the depth of closure, or the depth beyond which the bottom doesn't change with storms, was calculated.

$$h_c = 2 H + 11 \sigma_H$$

where:

$h_c$  is the depth of closure

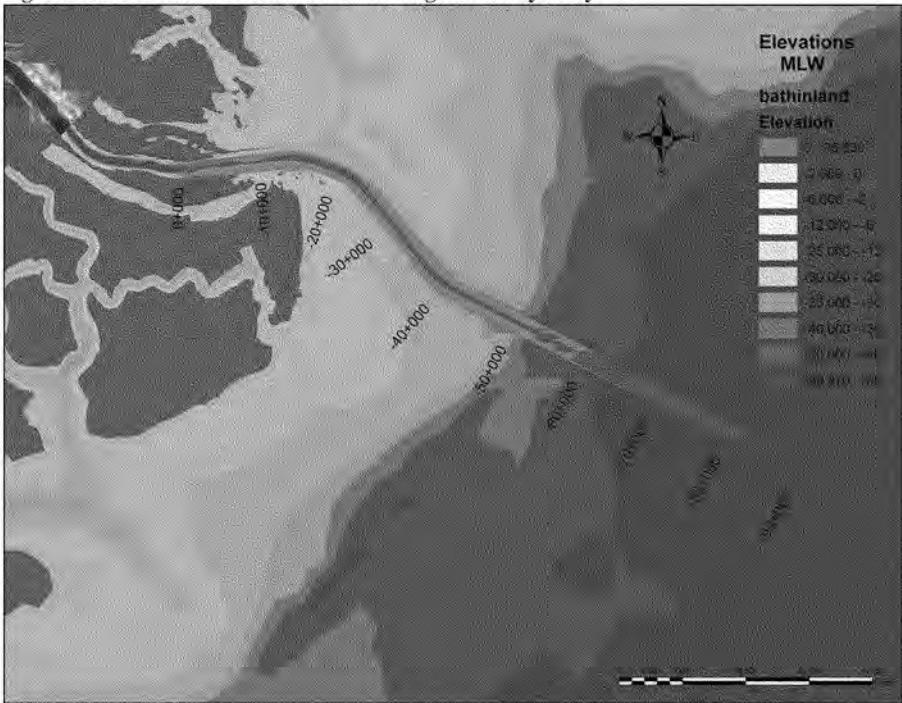
$H$  is the annual mean significant wave height

$\sigma_H$  is the standard deviation of significant wave height

Using, in the above equation, an annual mean significant wave height of 3.28 ft and a standard deviation of 1.64 ft from Station 368 of the Wave Information Study database, <http://frf.usace.army.mil/wis>, produces a depth of closure of 24.6 ft. As will be shown in the following section on advance maintenance, the shoals in the entrance channel rarely rise above elevation -40 ft, MLLW. Sediment that is presently transported into the entrance channel remains there until it is dredged, and an increase in depth will not make the entrance channel a more effective trap. The shoaling in the entrance channel is a function of the amount of sand transported to it, which is then trapped in it.

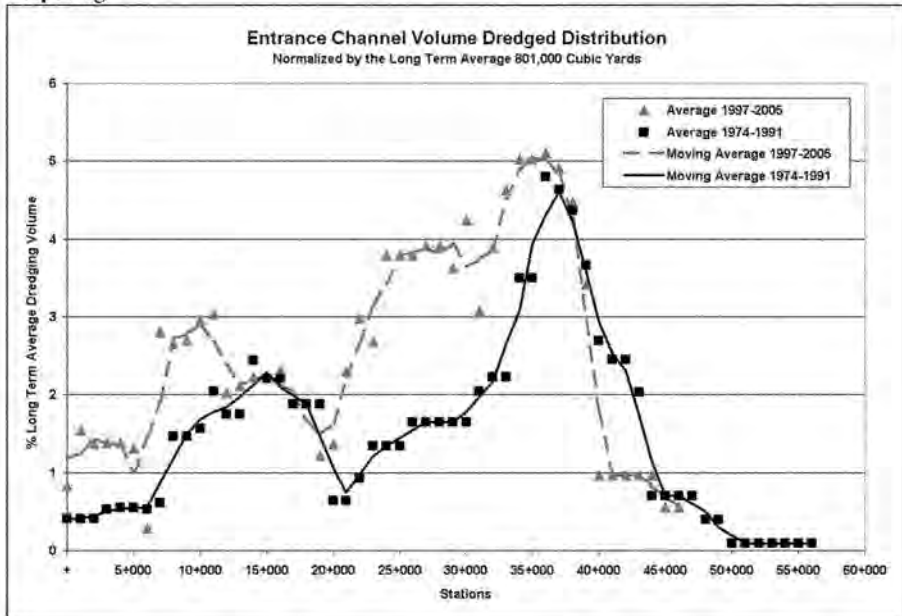
Another indication that the entrance channel is a total interdiction of the sediment entering the inlet environment is that the entrance channel completely cuts through the inlet's ocean bar. The ocean bar is the end product of the integrated effects of tidal currents, wave action and the associated sediment transport and deposition. Channel depths deeper than the depth at which the seaward tip of the ocean bar meets the offshore sea bottom will cause the channel to be a total interdiction of the littoral drift. The ocean bar does not extend beyond the 30 to 35 foot depth band. This is in agreement with the shoaling distribution along the entrance channel, which has virtually no shoaling beyond Station -50+000. See **Figure 10.3.5-1**.

**Figure 10.3.5-1: Entrance Channel Stationing and Bathymetry**



Maintenance dredging records for the entrance channel were available for the period 1974-2005. Dredging volumes for the entrance channel were also available from annual reports for the period 1975-2002. The data from the dredging records reflect the total volume dredged in a calendar year. The annual reports give the volume dredged that was paid for in a fiscal year. There is a general agreement between the two data sets, but the dredging record data appears to be missing several years. Both data sets show an increase in dredging of over 100,000 cubic yards from the pre- to post-1994 deepening periods. See **Figure 10.3.5-2**. The explanation for the apparent shoaling increase is due the difference in length of records of the pre- and post-deepening periods. The pre-deepening period is 19 years long and contains a cycle of both high and low shoaling periods. The post-deepening period is 8 years and contains only a high shoaling period with shoaling magnitudes comparable to those of the pre-deepening high shoaling period.

**Figure 10.3.5-2: Entrance Channel Volume Dredged Distribution Pre- and Post- the 1994 Deepening**



The entrance channel will be lengthened as a result of deepening. The channel length increases beyond Station -60+000 are shown in **Table 10.3.5-1** for a range of channel depths. The average annual volume dredged from the entrance channel reach between Stations -50+000 and -60+000 is 300 cubic yards per 1,000 ft of channel. Applying this rate for the channel increases gives the volume increases shown in **Table 10.3.5-1** for each incremental depth.

**Table 10.3.5-1: Entrance Channel Extension and Estimated Annual Maintenance**

| SHEP Entrance Channel Depth Alternative (ft below MLLW) | Length (Ft) | Length (Mi) | Estimated Annual Maintenance (Cy) |
|---------------------------------------------------------|-------------|-------------|-----------------------------------|
| 46                                                      | 35,700      | 6.8         | 10,710                            |
| 47                                                      | 36,900      | 7.0         | 11,070                            |
| 48                                                      | 37,500      | 7.1         | 11,250                            |
| 49                                                      | 37,700      | 7.1         | 11,310                            |
| 50                                                      | 38,600      | 7.3         | 11,580                            |

### 10.3.6 Shoaling Response and Advance Maintenance Features

Advance maintenance is authorized for Savannah Harbor to reduce the overall maintenance costs by decreasing the frequency of dredging. Dredging frequency is determined based on monthly project condition surveys. The condition surveys are taken along the four centerlines of the channel's quarters. When a shoal two ft or more above the project depth occurs in two adjacent quarters, a contractor is directed to remove the shoal. Analysis of the minimum depths shown on condition surveys taken between January 1997 and January 2005 indicate the existing advance maintenance areas, with the exception of Kings Island range, are providing acceptable navigation depths. The shoaling pattern is not predicted to change with future depth increases and the present advance maintenance areas do not need to be shifted due to future depth increases.

However, as discussed previously, discontinued use of the sediment basin, a mitigation feature under consideration to reduce the salinity moving up Back River, will cause changes in the shoaling pattern. The maximum shoal increases along the centerline of each quadrant for each reach, in the affected area, was identified and are listed in **Table 10.3.6-1**. Further analysis of these predicted shoaling amounts resulted in the associated advance maintenance depth increases shown in **Table 10.3.6-1**. The current advance maintenance relative to project depth in the Bight Channel Range will be adequate without the operation of the sediment basin. The other three ranges impacted have additional advance maintenance depth increases of 2 or 4 ft.

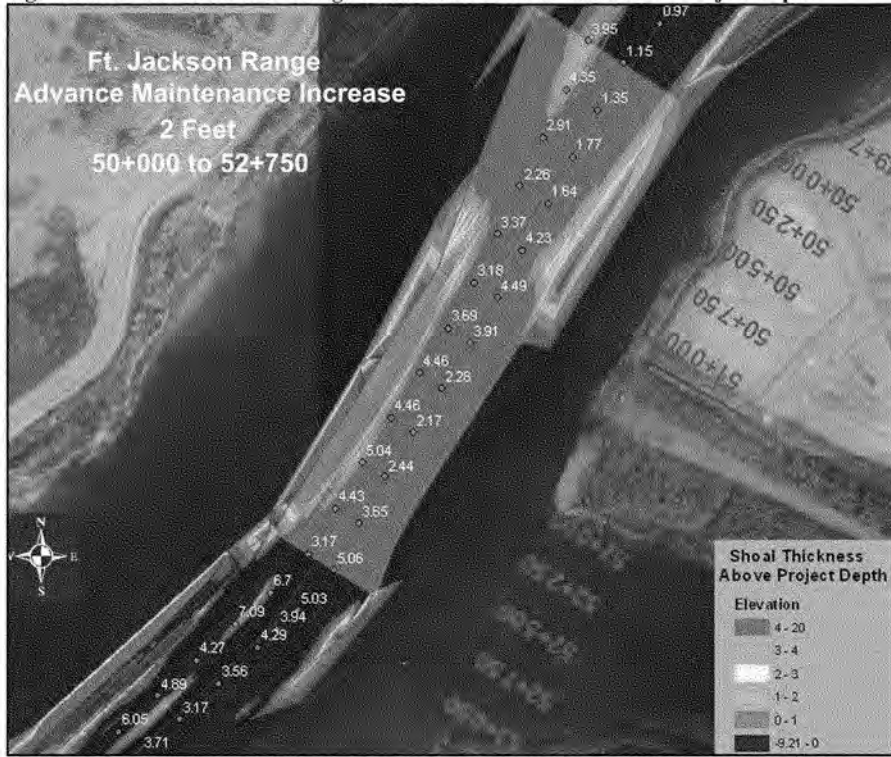
**Figures 10.3.6-1 to 10.3.6-3** illustrate the predicted shoal increase above the project depth. The area where the advance maintenance may need to be increased is shown as a shaded area.

The predicted shoaling changes may necessitate changes to the advance maintenance program. However, the future shoaling cannot be predicted precisely. By allowing the harbor to stabilize after SHEP construction, the shoaling patterns would likely be established, and at that point, a determination can be made to adjust the advance maintenance program to benefit O&M practices. If that determination is made, approvals to implement modifications to the program will be initiated through the normal business process.

**Table 10.3.6-1: Maximum Shoal Increases of Each Channel Quadrant & Advance Maintenance Increases**

|                                    | Left Outside Quadrant (ft) | Left Inside Quadrant (ft) | Right Inside Quadrant (ft) | Right Outside Quadrant (ft) | Advance Maintenance Increase (ft) |
|------------------------------------|----------------------------|---------------------------|----------------------------|-----------------------------|-----------------------------------|
| The Bight Channel 41+000 to 50+000 | 5.41                       | 3.08                      | 3.63                       | 4.74                        | None                              |
| Ft. Jackson Range 50+000 to 54+000 | 6.90                       | 5.06                      | 7.51                       | 10.24                       | 2                                 |
| Oglethorpe Range 54+000 to 61+000  | 7.28                       | 6.09                      | 7.81                       | 9.36                        | 4                                 |
| Wrecks Channel 61+000 to 70+000    | 8.41                       | 4.61                      | 3.63                       | 3.58                        | 2                                 |

**Figure 10.3.6-1: Fort Jackson Range Predicted Shoal Thickness Above Project Depth**

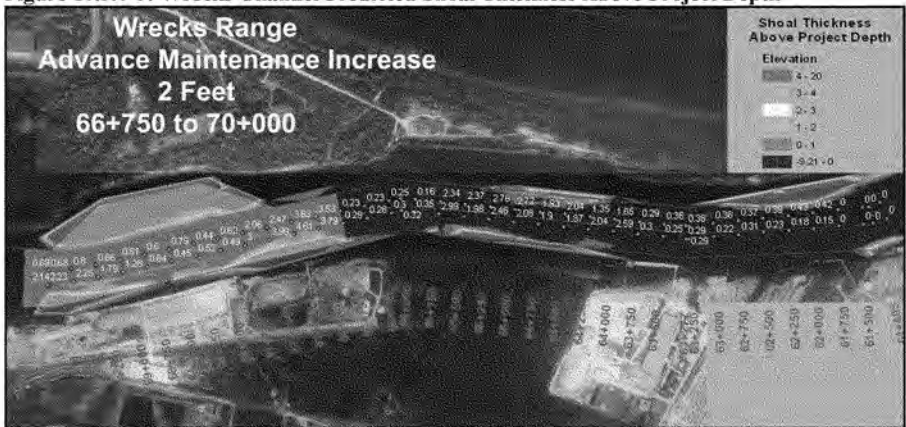


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Figure 10.3.6-2: Oglethorpe Range Predicted Shoal Thickness Above Project Depth



Figure 10.3.6-3: Wrecks Channel Predicted Shoal Thickness Above Project Depth



### 10.3.7 Shoaling Response and Lazaretto Creek

Lazaretto Creek is located near the mouth of the Savannah River in the northeastern section of Chatham County, GA. It connects the South Channel of the Savannah River with the Tybee Creek. The northern entrance to Lazaretto Creek is across from the Fort Pulaski National Monument on Cockspar Island and the south entrance is opposite the Shad River on Wilmington Island. Lazaretto Creek is approximately 7 miles long and is surrounded by saltwater marsh. There are commercial fishing and recreational boating docks on Lazaretto Creek at its northern end, on both sides of the Highway 80 Bridge. See **Figure 10.3.7-1**.

The South Channel is incorporated within the hydrodynamic model grid. Velocity comparisons with and without SHEP were made on South Channel at the entrance to Lazaretto Creek to determine if the SHEP impacts shoaling in this area. Model output indicates no major velocity or current pattern changes within this area; therefore, shoaling patterns are not expected to change from the current condition.

This area is not typically surveyed as part of the Federal navigation project. However, hydrographic surveys taken in 1997 indicate depths at the mouth of Lazaretto Creek at the South Channel confluence range from 7.5 ft below MLLW to 32.7 ft below MLLW. Additional surveys within this area taken in 2006 do not indicate major shoaling shifts.



**Figure 10.3.7-1: Lazaretto Creek**



## 10.4 CONCLUSIONS

- The Savannah Harbor Project captures all of the sediment that enters the harbor. The last channel deepening did not change the inner harbor shoaling volume, and future depth increases are predicted not to increase the shoaling volume.
- The entrance channel is a sediment sink that is a total interdiction of the littoral transport. Increases in depth will not increase the channel's ability to capture sediment.
- Based on the small predicted change in the salinity distribution for Plan 6a, implementation of Plan 6a will not change the shoaling distribution from the 6 foot deepening plan without mitigation.
- The existing advance maintenance areas, with the exception of the Kings Island range, are generally allowing an annual maintenance cycle without unacceptably encroaching above the authorized channel depth.
- If the operation of the sediment basin is discontinued, the advance maintenance depth in sections of the Fort Jackson Range, the Oglethorpe Range, and the Wrecks Channel Range may need to be deepened 2 to 4 ft.
- Shoaling is anticipated to shift from the adjacent channel into the proposed meeting areas.

## 11.0 DREDGING AND DISPOSAL OF NEW WORK MATERIAL

The following sections summarize the *Dredged Material Management Plan* (DMMP) for SHEP. The full DMMP can be found in the Engineering Investigations Supplemental Materials.

### 11.1 INNER HARBOR

#### 11.1.1 Inner Harbor Dredging Volumes

**Table 11.1-1** summarizes the volume of material to be dredged from the inner harbor for each depth alternative based on the recommended channel alignment including meeting areas, bend wideners, currently authorized advance maintenance, and over-depth.

**Table 11.1-1: New Work Inner Harbor Dredging Volumes**

| Stations                 | 44 ft<br>Project<br>(cy) | 45 ft<br>Project<br>(cy) | 46 ft<br>Project<br>(cy) | 47 ft<br>Project<br>(cy) | 48 ft<br>Project<br>(cy) |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 4+000 to 6+375           | 48,128                   | 87,346                   | 130,559                  | 174,073                  | 217,263                  |
| 6+375 to 30+000          | 913,871                  | 1,372,897                | 1,840,479                | 2,308,262                | 2,775,041                |
| 30+000 to 45+000         | 684,583                  | 1,052,928                | 1,426,462                | 1,802,866                | 2,181,609                |
| 45+000 to 51+000         | 324,752                  | 508,740                  | 699,013                  | 892,307                  | 1,088,128                |
| 51+000 to 57+000         | 464,032                  | 602,960                  | 743,122                  | 883,874                  | 1,025,450                |
| 57+000 to 67+000         | 415,297                  | 621,905                  | 828,620                  | 1,035,585                | 1,242,896                |
| 67+000 to 80+125         | 444,210                  | 691,727                  | 944,611                  | 1,196,291                | 1,446,786                |
| 80+125 to 90+000         | 380,724                  | 570,368                  | 759,169                  | 946,436                  | 1,132,066                |
| 90+000 to 103+000        | 1,438,457                | 1,803,823                | 2,169,594                | 2,533,434                | 2,895,175                |
| Channel Subtotal (cy)    | 5,114,054                | 7,312,694                | 9,541,629                | 11,773,128               | 14,004,414               |
|                          |                          |                          |                          |                          |                          |
| Long Island Meeting Area | 350,859                  | 384,096                  | 417,783                  | 450,941                  | 484,231                  |
| Oglethorpe Meeting Area  | 362,348                  | 384,089                  | 405,461                  | 426,336                  | 446,541                  |
| Meeting Area Subtotal    | 713,207                  | 768,185                  | 823,244                  | 877,277                  | 930,772                  |
|                          |                          |                          |                          |                          |                          |
| Total New Work (cy)      | 5,827,261                | 8,080,879                | 10,364,873               | 12,650,405               | 14,935,186               |

### 11.1.1.1 Cadmium Laden Dredged Material

Sediment testing and analyses in 1997 and 2001 for the Savannah Harbor Expansion Project indicated a potential for elevated levels of cadmium associated with the Miocene clay layer. Because of this potential, Phase 2 sediment testing in 2005 looked at the concentration and distribution of cadmium within new work sediments. Analysis of the sediment testing data resulted in the following recommendations:

- New work sediments from the reaches 6+375 to 45+000, 51+000 to 57+000 and 80+125 to 90+000 should be isolated within a CDF and capped/covered with sediment from another reach. The high cadmium sediments should not be disturbed further and should not be allowed to be later excavated and placed in any exposed upland area.
- Once a CDF is selected to receive the sediment, the high cadmium sediments should be pumped into the area first. Once placement of sediments from this reach is completed, markers should immediately be placed on the surface of the sediment, to allow easy determination of when the proper cap/cover depth has been attained. At least 1 foot of additional sediment from another reach should then be placed in the area as soon as practicable, but as part of the SHEP, to ensure minimal environmental impacts from birds feeding within the CDF. Due to expected variability in construction techniques, the project design will use 2 ft of capping/covering sediments.

The locations and volumes of material with elevated cadmium concentrations are shown in **Table 11.1.1.1-1**. Current plans call for using disposal facilities 14A and 14B for the placement of cadmium-laden material with the emphasis of placing as much material as possible in 14A. During the design phase further analysis could result in a consolidation of all the cadmium-laden sediments in 14A. The current, conservative placement plan for dredge material containing cadmium for each project depth can be found in **Tables 11.2-1** through **11.2-5** in the next Section.

**Table 11.1.1.1-1: Reaches with Elevated Cadmium Levels**

| Station          | Volume of Material (cy) |
|------------------|-------------------------|
| 6+375 to 45+000  | 4,562,069               |
| 51+000 to 57+000 | 1,101,114               |
| 80+125 to 90+000 | 946,436                 |
| Total            | 6,609,619               |

### 11.1.2 Inner Harbor Disposal

Material dredged from the inner harbor will be placed in upland confined disposal sites. The sites designated for placement of material were based on availability due to scheduled dike raisings, drying phases during construction, and annual channel maintenance needs. The disposal facilities that will be used for the deepening project over the construction period are 12A, 14A and 14B and Jones/Oysterbed Island (JOI). Areas 2A and 13A will not be utilized to dispose of new work material. They will exclusively hold annual maintenance dredged material when not in a drying phase or undergoing dike raising. See **Tables 11.2-1** through **11.2-5** for calculated dredged quantities and designated disposal facilities for each project depth.

**Table 11.2-1: 48 ft Project Depth Dredging Sequence (designating CDFs 14A and 14B for Cadmium)**

| Description    | Inner Harbor Stations | Dredged Material (cy) | Confined Disposal Facility (CDF) | Notes       |
|----------------|-----------------------|-----------------------|----------------------------------|-------------|
| O&M            | 4+000 to 57+000       | 3,563,754             | 12A                              |             |
| New Work       | 4+000 to 6+375        | 217,263               | JOI                              |             |
| New Work       | 6+375 to 30+000       | 3,259,272             | 14B                              | Cadmium     |
| New Work       | 30+000 to 45+000      | 2,181,609             | 14A                              | Cadmium     |
| New Work       | 51+000 to 57+000      | 1,251,494             | 14A                              | Cadmium     |
| New Work       | 80+125 to 90+000      | 1,555,112             | 14A                              | Cadmium     |
| New Work       | 45+000 to 51+000      | 1,088,128             | 12A                              |             |
| New Work + O&M | 57+000 to 67+000      | 2,631,872             | 12A                              |             |
| New Work + O&M | 67+000 to 80+125      | 2,387,645             | 12A                              |             |
| New Work + O&M | 90+000 to 93+280      | 1,259,825             | 12A                              |             |
| New Work + O&M | 93+280 to 98+140      | 1,860,000             | 14B                              | Cap for 14B |
| New Work + O&M | 98+140 to 103+000     | 1,860,000             | 14A                              | Cap for 14A |
| Total          |                       | 23,115,974            |                                  |             |

**Table 11.2-2: 47 ft Project Depth Dredging Sequence (designating CDFs 14A and 14B for Cadmium)**

| Description    | Inner Harbor Stations | Dredged Material (cy) | Confined Disposal Facility (CDF) | Notes       |
|----------------|-----------------------|-----------------------|----------------------------------|-------------|
| New Work + O&M | 4+000 to 6+375        | 248,815               | JOI                              |             |
| New Work + O&M | 6+375 to 36+000       | 4,663,278             | 14B                              | Cadmium     |
| New Work + O&M | 36+000 to 45+000      | 1,825,726             | 14A                              | Cadmium     |
| New Work + O&M | 51+000 to 57+000      | 1,857,054             | 14A                              | Cadmium     |
| New Work + O&M | 80+125 to 90+000      | 1,369,482             | 14A                              | Cadmium     |
| New Work + O&M | 45+000 to 51+000      | 1,698,443             | 12A                              |             |
| New Work + O&M | 57+000 to 67+000      | 2,021,557             | 12A                              |             |
| New Work + O&M | 67+000 to 80+125      | 2,528,753             | 12A                              |             |
| New Work + O&M | 90+000 to 103+000     | 898,084               | 12A                              |             |
| New Work + O&M | 90+000 to 103+000     | 1,860,000             | 14B                              | Cap for 14B |
| New Work + O&M | 90+000 to 103+000     | 1,860,000             | 14A                              | Cap for 14A |
| Total          |                       | 20,831,192            |                                  |             |

**Table 11.2-3: 46 ft Project Depth Dredging Sequence (designating CDFs 14A and 14B for Cadmium)**

| Description    | Inner Harbor Stations | Dredged Material (cy) | Confined Disposal Facility (CDF) | Notes       |
|----------------|-----------------------|-----------------------|----------------------------------|-------------|
| New Work + O&M | 4+000 to 6+375        | 205,301               | JOI                              |             |
| New Work + O&M | 6+375 to 30+000       | 2,972,789             | 14B                              | Cadmium     |
| New Work + O&M | 30+000 to 45+000      | 2,638,870             | 14A                              | Cadmium     |
| New Work + O&M | 51+000 to 57+000      | 1,707,141             | 14A                              | Cadmium     |
| New Work + O&M | 80+125 to 90+000      | 1,182,215             | 14A                              | Cadmium     |
| New Work + O&M | 45+000 to 51+000      | 1,505,149             | 12A                              |             |
| New Work + O&M | 57+000 to 67+000      | 2,214,851             | 12A                              |             |
| New Work + O&M | 67+000 to 80+125      | 1,865,100             | 12A                              |             |
| New Work + O&M | 90+000 to 103+000     | 534,244               | 12A                              |             |
| New Work + O&M | 90+000 to 103+000     | 1,860,000             | 14B                              | Cap for 14B |
| New Work + O&M | 90+000 to 103+000     | 1,860,000             | 14A                              | Cap for 14A |
| Total          |                       | 18,545,660            |                                  |             |

**Table 11.2-4: 45 ft Project Depth Dredging Sequence (designating CDFs 14A and 14B for Cadmium)**

| Description    | Inner Harbor Stations | Dredged Material (cy) | Confined Disposal Facility (CDF) | Notes       |
|----------------|-----------------------|-----------------------|----------------------------------|-------------|
| New Work + O&M | 4+000 to 6+375        | 162,088               | JOI                              |             |
| New Work + O&M | 6+375 to 30+000       | 2,482,781             | 14B                              | Cadmium     |
| New Work + O&M | 30+000 to 45+000      | 2,254,075             | 14A                              | Cadmium     |
| New Work + O&M | 51+000 to 57+000      | 1,557,444             | 14A                              | Cadmium     |
| New Work + O&M | 80+125 to 90+000      | 993,414               | 14A                              | Cadmium     |
| New Work + O&M | 45+000 to 51+000      | 1,314,876             | 14B                              | Cap for 14B |
| New Work + O&M | 57+000 to 67+000      | 545,124               | 14B                              | Cap for 14B |
| New Work + O&M | 57+000 to 67+000      | 1,860,000             | 14A                              | Cap for 14A |
| New Work + O&M | 67+000 to 80+125      | 1,563,391             | 12A                              |             |
| New Work + O&M | 90+000 to 103+000     | 3,888,473             | 12A                              |             |
| Total          |                       | 16,621,666            |                                  |             |

**Table 11.2-5: 44 ft Project Depth Dredging Sequence (designating CDFs 14A and 14B for Cadmium)**

| Description    | Inner Harbor Stations | Dredged Material (cy) | Confined Disposal Facility (CDF) | Notes       |
|----------------|-----------------------|-----------------------|----------------------------------|-------------|
| New Work + O&M | 4+000 to 6+375        | 122,870               | JOI                              |             |
| New Work + O&M | 6+375 to 30+000       | 2,003,174             | 14B                              | Cadmium     |
| New Work + O&M | 30+000 to 45+000      | 1,873,074             | 14A                              | Cadmium     |
| New Work + O&M | 51+000 to 57+000      | 1,408,733             | 14A                              | Cadmium     |
| New Work + O&M | 80+125 to 90+000      | 803,770               | 14A                              | Cadmium     |
| New Work + O&M | 45+000 to 51+000      | 1,130,888             | 14B                              | Cap for 14B |
| New Work + O&M | 57+000 to 70+000      | 729,112               | 14B                              | Cap for 14B |
| New Work + O&M | 57+000 to 70+000      | 1,612,556             | 14A                              | Cap for 14A |
| New Work + O&M | 70+000 to 73+100      | 247,444               | 14A                              | Cap for 14A |
| New Work + O&M | 73+100 to 80+125      | 553,320               | 12A                              |             |
| New Work + O&M | 90+000 to 103+000     | 3,523,107             | 12A                              |             |
| Total          |                       | 14,008,048            |                                  |             |

**Table 11.2-6** details the dredge material for the 47 ft project depth along with the CDF capacity before and after the material is placed.

**Table 11.2-6: CDF Capacity With & Without Project Dredging Operations**

| Inner Harbor Stations | Without Project   |                                  | CDF Present Capacity (cy) | 47 ft Project         |                                  | CDF Present Capacity (cy) |
|-----------------------|-------------------|----------------------------------|---------------------------|-----------------------|----------------------------------|---------------------------|
|                       | O&M Material (cy) | Confined Disposal Facility (CDF) |                           | Dredged Material (cy) | Confined Disposal Facility (CDF) |                           |
| 0+000 to 4+000        | 76,000            | 13B                              | 11,900,000                | -                     | -                                |                           |
| 4+000 to 6+375        | 26,719            | 13B                              | 11,900,000                | 248,815               | JOI                              | 7,200,000                 |
| 6+375 to 36+000       | 605,781           | 13B                              | 11,900,000                | 4,663,278             | 14B                              | 9,100,000                 |
| 36+000 to 45+000      | 406,500           | 13B                              | 11,900,000                | 1,825,726             | 14A                              | 6,200,000                 |
| 51+000 to 57+000      | 622,800           | 13A                              | 32,400,000                | 1,857,054             | 14A                              | 6,200,000                 |
| 80+125 to 90+000      | 318,633           | 13A                              | 32,400,000                | 1,369,482             | 14A                              | 6,200,000                 |
| 45+000 to 51+000      | 553,800           | 13B                              | 11,900,000                | 1,698,443             | 12A                              | 24,000,000                |
| 57+000 to 67+000      | 0                 | 13A                              | 32,400,000                | 2,021,557             | 12A                              | 24,000,000                |
| 67+000 to 80+125      | 1,038,000         | 13A                              | 32,400,000                | 2,528,753             | 12A                              | 24,000,000                |
| 90+000 to 103+000     | 641,700           | 13A                              | 32,400,000                | 898,084               | 12A                              | 24,000,000                |
| 90+000 to 103+000     | 1,706,067         | 13A                              | 32,400,000                | 1,860,000             | 14B                              | 9,100,000                 |
| 90+000 to 103+000     | 229,000           | 2A                               | 4,400,000                 | 1,860,000             | 14A                              | 6,200,000                 |
| Total                 | 6,225,000         |                                  |                           | 20,831,192            |                                  |                           |

SHEP will place 12.65 million cy of new work material in CDFs which were established for the placement of sediments for the Savannah Harbor Navigation Project. As part of that placement, the Expansion Project will replace the sediment storage capacity that it used to place the new work material.

The following tables (**Table 11.2-7** and **11.2-8**) detail the disposal area rotation for the annual maintenance material disposal plan for the inner harbor with and without-project for the 50 year project life. The schedule is based on the reaches (station to station) and quantities laid out in **Table 11.2-2** for the 47 ft project depth. Annual maintenance dredging will be going on in conjunction with the new work dredging and will not impact the required 20-year capacity as required by the DMMP. Any loss in capacity to new work material will be replaced by the new work project. Deposition of the new work sediments is shown beginning in 2014 and ending in 2016 (background color = orange).

Table 11.2-7: Inner Harbor New Work and Annual Maintenance Material Disposal Plan 2010–2066 (47 ft MLLW Project Depth)

| Fiscal Year <sup>a</sup> | Confined Disposal Area |            |                             |           |            |            |            |           |           |                  | TOTALS |  |  |
|--------------------------|------------------------|------------|-----------------------------|-----------|------------|------------|------------|-----------|-----------|------------------|--------|--|--|
|                          | 2A                     | 12A        | 13A                         | 13B       | 14A        | 14B        | J/O        | O&M       | New Work  | O&M and New Work |        |  |  |
| 2010                     | 229,000                | 4,431,000  | BUILD DIKE<br>Breach X dike | 782,500   | BUILD DIKE | 782,500    | DRYING     | 6,225,000 |           |                  |        |  |  |
| 2011                     | 229,000                | DRYING     | 4,431,000                   | 1,565,000 | BUILD DIKE | DRYING     | BUILD DIKE | 6,225,000 |           |                  |        |  |  |
| 2012                     | 229,000                | DRYING     | 4,431,000                   | 1,565,000 | BUILD DIKE | BUILD DIKE | BUILD DIKE | 6,225,000 |           |                  |        |  |  |
| 2013                     | 229,000                | BUILD DIKE | 4,431,000                   | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000 |           |                  |        |  |  |
| 2014                     | DRYING                 | 4,828,500  | DRYING                      | 782,500   | DRYING     | 2,299,000  | 248,815    | 5,611,000 | 2,547,815 | 8,158,815        |        |  |  |
| 2015                     | DRYING                 | 2,323,084  | DRYING                      | 25,719    | 4,575,780  | 2,364,278  | 0          | 1,711,719 | 9,263,142 | 10,974,861       |        |  |  |
| 2016                     | DRYING                 | 1,685,000  | BUILD DIKE                  | DRYING    | 2,336,482  | 1,860,000  | 1,489,000  | 3,859,000 | 9,020,235 | 12,879,235       |        |  |  |
|                          |                        | 4,823,753  |                             |           | DRYING     | DRYING     |            |           |           |                  |        |  |  |
| 2017                     | FULL                   | DRYING     | 4,660,000                   | DRYING    | DRYING     | DRYING     | 1,565,000  | 6,225,000 |           |                  |        |  |  |
| 2018                     |                        | DRYING     | 4,660,000                   | DRYING    | BUILD DIKE | BUILD DIKE | 1,565,000  | 6,225,000 |           |                  |        |  |  |
| 2019                     |                        | BUILD DIKE | 4,660,000                   | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000 |           |                  |        |  |  |
| 2020                     |                        | 4,660,000  | DRYING                      | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000 |           |                  |        |  |  |
| 2021                     |                        | 4,660,000  | DRYING                      | DRYING    | 782,500    | 782,500    | BUILD DIKE | 6,225,000 |           |                  |        |  |  |
| 2022                     |                        | 4,660,000  | BUILD DIKE                  | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000 |           |                  |        |  |  |
| 2023                     |                        | DRYING     | 4,660,000                   | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000 |           |                  |        |  |  |
| 2024                     |                        | DRYING     | 4,660,000                   | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000 |           |                  |        |  |  |
| 2025                     |                        | BUILD DIKE | 4,660,000                   | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000 |           |                  |        |  |  |
| 2026                     |                        | 4,660,000  | DRYING                      | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000 |           |                  |        |  |  |
| 2027                     |                        | 4,660,000  | DRYING                      | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000 |           |                  |        |  |  |
| 2028                     |                        | 4,660,000  | DRYING                      | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000 |           |                  |        |  |  |
| 2029                     |                        | DRYING     | 4,660,000                   | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000 |           |                  |        |  |  |
| 2030                     |                        | DRYING     | 4,660,000                   | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000 |           |                  |        |  |  |
| 2031                     |                        | BUILD DIKE | 4,660,000                   | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000 |           |                  |        |  |  |
| 2032                     |                        | 4,660,000  | DRYING                      | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000 |           |                  |        |  |  |

Continued on next page



Table 11.2-7: Inner Harbor New Work and Annual Maintenance Material Disposal Plan 2010 -2066 (47 ft MLLW Project Depth)  
(continued from previous page)

| Fiscal Year <sup>a</sup> | Confined Disposal Area |            |            |            |            |            |            |           |          |                  | TOTALS |  |
|--------------------------|------------------------|------------|------------|------------|------------|------------|------------|-----------|----------|------------------|--------|--|
|                          | 2A                     | 12A        | 13A        | 13B        | 14A        | 14B        | J/O        | O&M       | New Work | O&M and New Work |        |  |
| 2033                     |                        | 4,660,000  | DRYING     | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |          |                  |        |  |
| 2034                     |                        | 4,660,000  | BUILD DIKE | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |          |                  |        |  |
| 2035                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |          |                  |        |  |
| 2036                     |                        | DRYING     | 4,660,000  | 782,500    | BUILD DIKE | DRYING     | 782,500    | 6,225,000 |          |                  |        |  |
| 2037                     |                        | BUILD DIKE | 4,660,000  | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |          |                  |        |  |
| 2038                     |                        | 4,660,000  | DRYING     | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |          |                  |        |  |
| 2039                     |                        | 4,660,000  | DRYING     | BUILD DIKE | 782,500    | 782,500    | DRYING     | 6,225,000 |          |                  |        |  |
| 2040                     |                        | 4,660,000  | BUILD DIKE | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |          |                  |        |  |
| 2041                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |          |                  |        |  |
| 2042                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |          |                  |        |  |
| 2043                     |                        | BUILD DIKE | 4,660,000  | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |          |                  |        |  |
| 2044                     |                        | 4,660,000  | DRYING     | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |          |                  |        |  |
| 2045                     |                        | 4,660,000  | DRYING     | DRYING     | 782,500    | 782,500    | BUILD DIKE | 6,225,000 |          |                  |        |  |
| 2046                     |                        | 4,660,000  | BUILD DIKE | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |          |                  |        |  |
| 2047                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |          |                  |        |  |
| 2048                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | BUILD DIKE | 782,500    | 6,225,000 |          |                  |        |  |
| 2049                     |                        | BUILD DIKE | 4,660,000  | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |          |                  |        |  |
| 2050                     |                        | 4,660,000  | DRYING     | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |          |                  |        |  |
| 2051                     |                        | 4,660,000  | DRYING     | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |          |                  |        |  |
| 2052                     |                        | 4,660,000  | BUILD DIKE | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |          |                  |        |  |
| 2053                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |          |                  |        |  |
| 2054                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |          |                  |        |  |
| 2055                     |                        | BUILD DIKE | 4,660,000  | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |          |                  |        |  |
| 2056                     |                        | 4,660,000  | DRYING     | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |          |                  |        |  |
| 2057                     |                        | 4,660,000  | DRYING     | BUILD DIKE | 782,500    | 782,500    | DRYING     | 6,225,000 |          |                  |        |  |

Continued on next page

Table 11.2-7: Inner Harbor New Work and Annual Maintenance Material Disposal Plan 2010 -2066 (47 ft MLLW Project Depth)  
(continued from previous page)

| Fiscal Year* | Confined Disposal Area    |                                                                                  |            |         |         |            |         | TOTALS    |          |
|--------------|---------------------------|----------------------------------------------------------------------------------|------------|---------|---------|------------|---------|-----------|----------|
|              | 2A                        | 12A                                                                              | 13A        | 13B     | 14A     | 14B        | J/O     | O&M       | New Work |
| 2058         |                           | 4,660,000                                                                        | BUILD DIKE | 782,500 | DRYING  | DRYING     | 782,500 | 6,225,000 |          |
| 2059         |                           | DRYING                                                                           | 4,660,000  | 782,500 | DRYING  | DRYING     | 782,500 | 6,225,000 |          |
| 2060         |                           | DRYING                                                                           | 4,660,000  | 782,500 | DRYING  | BUILD DIKE | 782,500 | 6,225,000 |          |
| 2061         |                           | BUILD DIKE                                                                       | 4,660,000  | DRYING  | 782,500 | 782,500    | DRYING  | 6,225,000 |          |
| 2062         |                           | 4,660,000                                                                        | DRYING     | DRYING  | 782,500 | 782,500    | DRYING  | 6,225,000 |          |
| 2063         |                           | 4,660,000                                                                        | DRYING     | DRYING  | 782,500 | 782,500    | DRYING  | 6,225,000 |          |
| 2064         |                           | 4,660,000                                                                        | BUILD DIKE | 782,500 | DRYING  | DRYING     | 782,500 | 6,225,000 |          |
| 2065         |                           | DRYING                                                                           | 4,660,000  | 782,500 | DRYING  | DRYING     | 782,500 | 6,225,000 |          |
| 2066         |                           | DRYING                                                                           | 4,660,000  | 782,500 | DRYING  | DRYING     | 782,500 | 6,225,000 |          |
|              |                           |                                                                                  |            |         |         |            |         |           |          |
| <b>Reach</b> | <b>Maintenance Volume</b> |                                                                                  |            |         |         |            |         |           |          |
| 0 to 50      | 1,565,000                 | JOL, 14B, 14A, 13B: Split Annual Volume in half to two available areas each year |            |         |         |            |         |           |          |
| 50 to 102    | 4,431,000                 | 12A, 13A: Use Area Available                                                     |            |         |         |            |         |           |          |
| 102 to 112   | 229,000                   | 2A or 12A, 13A: Use 2A when available                                            |            |         |         |            |         |           |          |
| Total        | 6,225,000                 |                                                                                  |            |         |         |            |         |           |          |

\*Based on Federal Fiscal Year 1 October to 30 September.

\*\*2A will be full in FY 2017 and no longer available for use.

Table 11.2-8: Inner Harbor Annual Maintenance Material Disposal Plan 2010 -2066 (Without Project Conditions)

| Fiscal<br>Year* | Confined Disposal Area |            |            |           |            |            |            | TOTAL<br>O&M |
|-----------------|------------------------|------------|------------|-----------|------------|------------|------------|--------------|
|                 | 2A                     | 12A        | 13A        | 13B       | 14A        | 14B        | J/O        |              |
| 2010            | 229,000                | 4,431,000  | BUILD DIKE | 782,500   | BUILD DIKE | 782,500    | DRYING     | 6,225,000    |
| 2011            | 229,000                | DRYING     | 4,431,000  | 1,565,000 | BUILD DIKE | DRYING     | BUILD DIKE | 6,225,000    |
| 2012            | 229,000                | DRYING     | 4,431,000  | 1,565,000 | DRYING     | DRYING     | BUILD DIKE | 6,225,000    |
| 2013            | 229,000                | BUILD DIKE | 4,431,000  | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000    |
| 2014            | DRYING                 | 4,660,000  | DRYING     | 782,500   | DRYING     | BUILD DIKE | 782,500    | 6,225,000    |
| 2015            | DRYING                 | 4,660,000  | DRYING     | 782,500   | BUILD DIKE | DRYING     | 782,500    | 6,225,000    |
| 2016            | DRYING                 | 4,660,000  | BUILD DIKE | DRYING    | DRYING     | DRYING     | 1,565,000  | 6,225,000    |
| 2017            | FULL                   | DRYING     | 4,660,000  | DRYING    | DRYING     | DRYING     | 1,565,000  | 6,225,000    |
| 2018            |                        | DRYING     | 4,660,000  | DRYING    | DRYING     | DRYING     | 1,565,000  | 6,225,000    |
| 2019            |                        | BUILD DIKE | 4,660,000  | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000    |
| 2020            |                        | 4,660,000  | DRYING     | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000    |
| 2021            |                        | 4,660,000  | DRYING     | DRYING    | 782,500    | 782,500    | BUILD DIKE | 6,225,000    |
| 2022            |                        | 4,660,000  | BUILD DIKE | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000    |
| 2023            |                        | DRYING     | 4,660,000  | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000    |
| 2024            |                        | DRYING     | 4,660,000  | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000    |
| 2025            |                        | BUILD DIKE | 4,660,000  | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000    |
| 2026            |                        | 4,660,000  | DRYING     | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000    |
| 2027            |                        | 4,660,000  | DRYING     | DRYING    | 782,500    | 782,500    | BUILD DIKE | 6,225,000    |
| 2028            |                        | 4,660,000  | DRYING     | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000    |
| 2029            |                        | DRYING     | 4,660,000  | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000    |
| 2030            |                        | DRYING     | 4,660,000  | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000    |
| 2031            |                        | BUILD DIKE | 4,660,000  | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000    |
| 2032            |                        | 4,660,000  | DRYING     | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000    |
| 2033            |                        | 4,660,000  | DRYING     | DRYING    | 782,500    | 782,500    | DRYING     | 6,225,000    |
| 2034            |                        | 4,660,000  | BUILD DIKE | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000    |
| 2035            |                        | DRYING     | 4,660,000  | 782,500   | DRYING     | DRYING     | 782,500    | 6,225,000    |

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Table 11.2-8: Inner Harbor Annual Maintenance Material Disposal Plan 2010–2066 (Without Project Conditions) (Continued)

| Fiscal Year <sup>a</sup> | Confined Disposal Area |            |            |            |            |            |            | TOTAL O&M |
|--------------------------|------------------------|------------|------------|------------|------------|------------|------------|-----------|
|                          | 2A                     | 12A        | 13A        | 13B        | 14A        | 14B        | J/O        |           |
| 2036                     |                        | DRYING     | 4,660,000  | 782,500    | BUILD DIKE | DRYING     | 782,500    | 6,225,000 |
| 2037                     |                        | BUILD DIKE | 4,660,000  | DRYING     | DRYING     | 782,500    | DRYING     | 6,225,000 |
| 2038                     |                        | 4,660,000  | DRYING     | DRYING     | DRYING     | 782,500    | DRYING     | 6,225,000 |
| 2039                     |                        | 4,660,000  | DRYING     | BUILD DIKE | BUILD DIKE | 782,500    | DRYING     | 6,225,000 |
| 2040                     |                        | 4,660,000  | BUILD DIKE | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |
| 2041                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |
| 2042                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |
| 2043                     |                        | BUILD DIKE | 4,660,000  | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |
| 2044                     |                        | 4,660,000  | DRYING     | DRYING     | DRYING     | 782,500    | DRYING     | 6,225,000 |
| 2045                     |                        | 4,660,000  | DRYING     | DRYING     | 782,500    | 782,500    | BUILD DIKE | 6,225,000 |
| 2046                     |                        | 4,660,000  | BUILD DIKE | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |
| 2047                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |
| 2048                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | BUILD DIKE | 782,500    | 6,225,000 |
| 2049                     |                        | BUILD DIKE | 4,660,000  | DRYING     | DRYING     | 782,500    | DRYING     | 6,225,000 |
| 2050                     |                        | 4,660,000  | DRYING     | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |
| 2051                     |                        | 4,660,000  | DRYING     | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |
| 2052                     |                        | 4,660,000  | BUILD DIKE | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |
| 2053                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |
| 2054                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |
| 2055                     |                        | BUILD DIKE | 4,660,000  | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |
| 2056                     |                        | 4,660,000  | DRYING     | DRYING     | 782,500    | 782,500    | DRYING     | 6,225,000 |
| 2057                     |                        | 4,660,000  | DRYING     | BUILD DIKE | 782,500    | 782,500    | DRYING     | 6,225,000 |
| 2058                     |                        | 4,660,000  | BUILD DIKE | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |
| 2059                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | DRYING     | 782,500    | 6,225,000 |
| 2060                     |                        | DRYING     | 4,660,000  | 782,500    | DRYING     | BUILD DIKE | 782,500    | 6,225,000 |

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Table 11.2-8: Inner Harbor Annual Maintenance Material Disposal Plan 2010 -2066 (Without Project Conditions) (Continued)

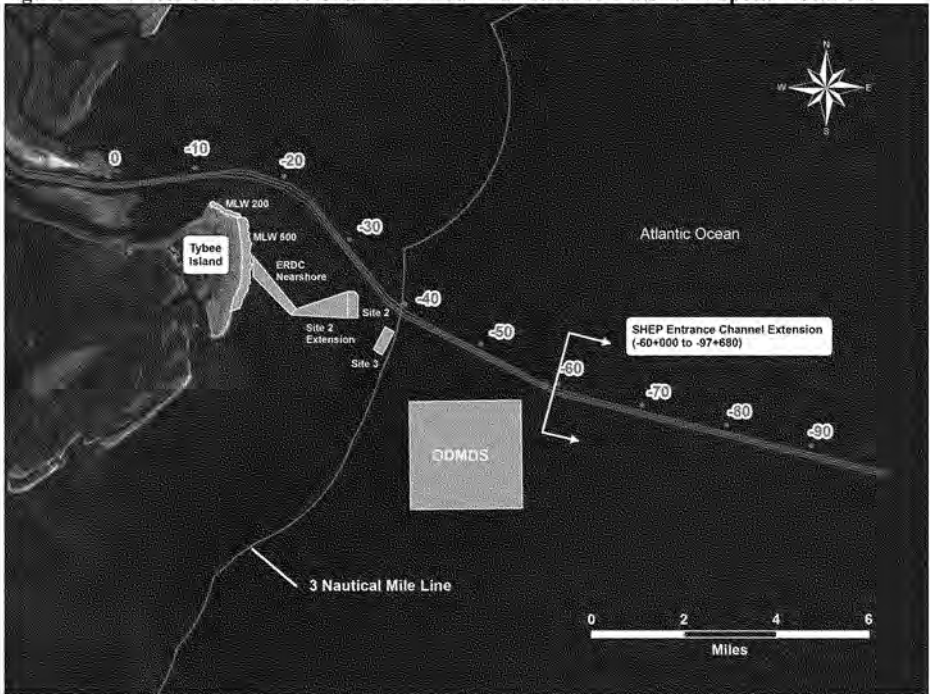
| Fiscal<br>Year <sup>a</sup> | Confined Disposal Area |            |            |         |         |         |         | TOTAL<br>O&M |
|-----------------------------|------------------------|------------|------------|---------|---------|---------|---------|--------------|
|                             | 2A                     | 12A        | 13A        | 13B     | 14A     | 14B     | J/O     |              |
| 2061                        |                        | BUILD DIKE | 4,660,000  | DRYING  | 782,500 | 782,500 | DRYING  | 6,225,000    |
| 2062                        |                        | 4,660,000  | DRYING     | DRYING  | 782,500 | 782,500 | DRYING  | 6,225,000    |
| 2063                        |                        | 4,660,000  | DRYING     | DRYING  | 782,500 | 782,500 | DRYING  | 6,225,000    |
| 2064                        |                        | 4,660,000  | BUILD DIKE | 782,500 | DRYING  | DRYING  | 782,500 | 6,225,000    |
| 2065                        |                        | DRYING     | 4,660,000  | 782,500 | DRYING  | DRYING  | 782,500 | 6,225,000    |
| 2066                        |                        | DRYING     | 4,660,000  | 782,500 | DRYING  | DRYING  | 782,500 | 6,225,000    |

## 11.2 ENTRANCE CHANNEL DISPOSAL

Currently, annual maintenance dredged material removed from the Entrance Channel is placed in the EPA-approved Ocean Dredged Material Disposal Site (ODMDS). See **Figure 11.2-1**. All dredged sediments from the SHEP Entrance Channel would be placed into the ODMDS or potentially upland CDFs.

In the Draft SHEP GRR, placement of materials in the nearshore was proposed as a beneficial use of dredged materials. Material with a fines content of 20 percent or less would have been placed into the nearshore sites and feeder berms in addition to placing material in the ODMDS. See **Figure 11.2-1**. The Georgia DNR-CRD and the City of Tybee Island have requested that these sites not be used for sediment placement from the project because they prefer material with a fines content of 10 percent or less. Consequently, these dredged material placement sites for new work were removed from the project. The Corps may use sites previously approved in the 1996 LTMS for placement of maintenance material (Site 2, Site 3, Site 2 Extension, ERDC Nearshore, MLW 200, MLW 500).

**Figure 11.2-1: Possible Entrance Channel Annual Maintenance Material Disposal Locations**



The volume of new work dredged sediment to be removed by project depth for the entrance channel including the extension is shown in **Table 11.2-1**. This material will be placed in the EPA approved ODMDS site.

**Table 11.2-1: Entrance Channel Volumes by Station of New Work Material for all Project Depths**

| Station            | 44 ft     | 45 ft     | 46 ft     | 47 ft     | 48 ft     |
|--------------------|-----------|-----------|-----------|-----------|-----------|
| -98+600 to -57+000 | 1,667,123 | 2,242,371 | 2,925,432 | 3,736,308 | 4,613,909 |
| -57+000 to -53+500 | 156,623   | 235,127   | 313,391   | 391,437   | 469,252   |
| -53+500 to -40+000 | 646,796   | 975,843   | 1,304,385 | 1,632,346 | 1,959,186 |
| -40+000 to -30+000 | 505,693   | 771,105   | 1,038,620 | 1,305,921 | 1,573,800 |
| -30+000 to -20+000 | 529,910   | 801,974   | 1,076,638 | 1,352,115 | 1,628,379 |
| -20+000 to -10+000 | 473,047   | 746,614   | 1,028,399 | 1,311,222 | 1,594,871 |
| -10+000 to 0+000   | 346,997   | 532,621   | 723,394   | 917,064   | 1,110,713 |
| 0+000 to +4+000    | 101,482   | 166,705   | 235,626   | 305,674   | 375,403   |

*\*Station -98+600 is the extended channel stationing for the 48 ft project depth. Channel stationing for the 47 ft project depth across the ocean bar terminates at Station -97+680.*

### 11.2.1 ODMDS Capacity Analysis

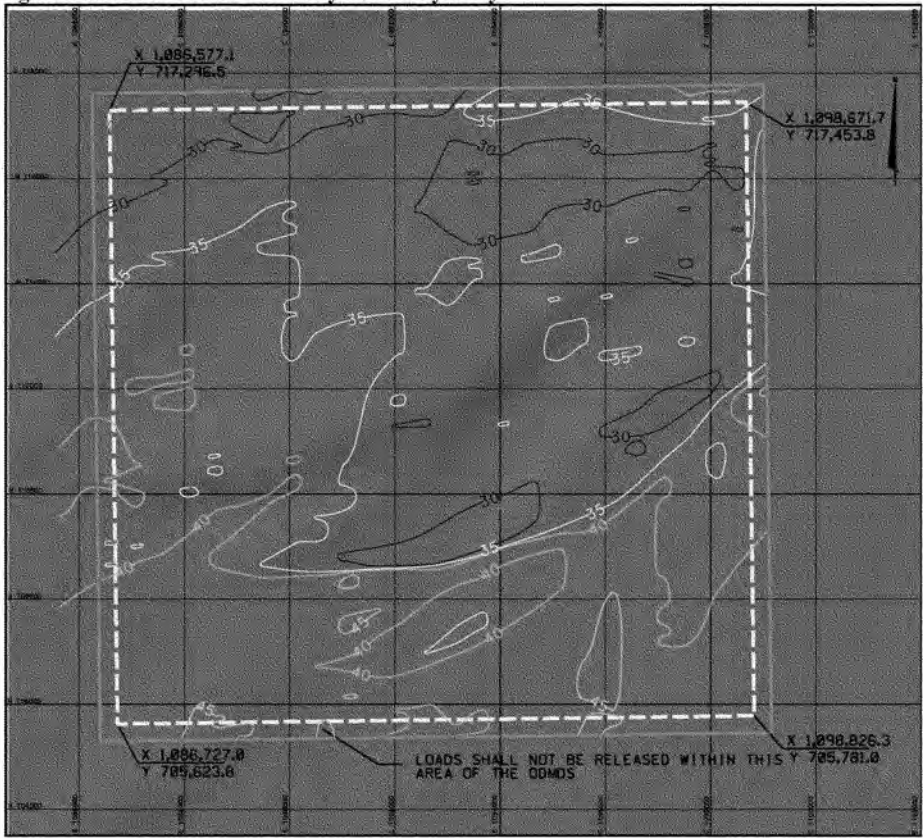
Two approaches were taken to determine future capacity of the ODMDS after placement of materials from the Savannah Harbor Expansion offshore dredging:

- The first analysis assumed that dredged material would primarily consist of sands (with no bulking factor) and that all deposited material would remain in the ODMDS area after placement.
- The alternative approach was to examine the last period of time when the ODMDS was used consistently and compare the dredged volumes removed from the channel that were placed in the ODMDS with the change in capacity of the ODMDS based on placement surveys over the same time period.

Differences in capacity were determined by using software in Bentley InRoads to determine surface areas and to make volume computations. Actual dredging volumes were obtained from dredging reports maintained in the Savannah District office.

The ODMDS boundary is shown in pink on **Figure 11.2.1-1**. To comply with 40 CFR §227.28 disposal shall occur no less than 330 feet (100 meters) inside the site boundaries. The ODMDS footprint (shown in yellow) for placement of material is 3,242 acres.

Figure 11.2.1-1: ODMDS Boundary and Bathymetry





The quantity of material shown in **Table 11.2.1-1** dredged from the entrance channel from 2002 to 2007 as well as the change in capacity of the ODMDS based on placement surveys made over the same time period. Results show that roughly 93% of the material dredged from the channel remains in the ODMDS after placement, possibly because of the presence of fines in the dredged material that do not settle out or may leave the area before settling or losses during the dredging process.

**Table 11.2.1-1: Material Dredged Versus ODMDS Change in Capacity**

| Year               | Quantity Dredged (cy) | ODMDS Capacity* (cy) |     |
|--------------------|-----------------------|----------------------|-----|
| 2002               | 186,537               | 57,836,270           |     |
| 2003               | 635,163               |                      |     |
| 2004               | 620,642               |                      |     |
| 2005               | 888,101               |                      |     |
| 2007               | 973,463               | 54,766,930           |     |
| Total Dredged      | 3,303,906             |                      |     |
| Change in Capacity |                       | 3,069,340            |     |
| percentage placed  |                       |                      | 93% |

\*ODMDS capacity is determined from the surface to -25 ft MLLW

**Tables 11.2.1-2 and 11.2.1-3** shows results of the remaining capacity of the ODMDS for existing conditions and assuming the material placed from the Savannah Harbor Expansion is either 1) the volume placed is equivalent to the volume dredged or 2) volume placed is equivalent to 93% of the material dredged, based on the results from **Table 11.2.1-1**. Results of both methods are based on the upper limit for material placement in the ODMDS as 25 ft below MLLW. **Table 11.2.1-3** shows results for both the 47 ft and 48 ft project. The capacity life is reduced for the deeper project because of the greater volume of material required to be removed/placed and increased maintenance as the deeper project requires a longer channel. The average annual Operations and Maintenance (O&M) dredge material volumes were developed previously based on historical dredging records. The volume of available undredged material that remains after dredging (primarily due to funding constraints) is also considered.

**Table 11.2.1-2: ODMDS Capacity (Existing Conditions)**

|                                                                |               |
|----------------------------------------------------------------|---------------|
| ODMDS capacity (2012)                                          | 57,087,926 cy |
| Average Annual O&M Dredge Volume                               | 1,057,721 cy  |
| Years Remaining until Capacity is Exceeded (without deepening) | 55            |

Given the constraints for the Savannah Harbor ODMDS of a surface area of 3,242 acres and upper height limit of 25 ft below MLLW, with materials added from the offshore channel for the 48 ft project depth, the remaining capacity for the ODMDS would last between 36 and 40 years depending on the volume of material placed. For the 47 ft project, capacity would last between 39 and 42 years. Without material from the Savannah Harbor Expansion Project there would be a 55 year capacity for holding annually dredged O&M material.

Table 1.2.1-3: ODMDS Capacity (With Project)

|                                                               | 46 ft depth<br>(44 ft project) | 46 ft depth<br>(44 ft project) | 47 ft depth<br>(45 ft project) | 47 ft depth<br>(45 ft project) | 48 ft depth<br>(46 ft project) | 48 ft depth<br>(46 ft project) | 49 ft depth<br>(47 ft project) | 49 ft depth<br>(47 ft project) | 50 ft depth<br>(48 ft project) | 50 ft depth<br>(48 ft project) |
|---------------------------------------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|
| Percentage of<br>Dredged Material<br>on ODMDS Floor           | 100%<br>placed                 | 93%<br>placed                  | 100%<br>placed                 | 93%<br>placed                  | 100%<br>placed                 | 93%<br>placed                  | 100%<br>placed                 | 93%<br>placed                  | 100%<br>placed                 | 93%<br>placed                  |
| 2014 Capacity<br>(after 2 yrs of<br>existing O&M)             | 54,972,484                     | 54,972,484                     | 54,972,484                     | 54,972,484                     | 54,972,484                     | 54,972,484                     | 54,972,484                     | 54,972,484                     | 54,972,484                     | 54,972,484                     |
| New Work<br>Quantity                                          | 4,326,189                      | 4,326,189                      | 6,305,655                      | 6,305,655                      | 8,410,259                      | 8,410,259                      | 10,646,413                     | 10,646,413                     | 12,950,110                     | 12,950,110                     |
| 2017 Capacity<br>(after new work<br>material)                 | 50,646,295                     | 50,949,128                     | 48,666,829                     | 49,108,225                     | 46,562,225                     | 47,150,943                     | 44,326,071                     | 45,071,320                     | 42,022,374                     | 42,928,881                     |
| Average Annual<br>O&M<br>Dredging Volume<br>(after expansion) | 1,066,299                      | 1,066,299                      | 1,066,587                      | 1,066,587                      | 1,066,738                      | 1,066,738                      | 1,066,778                      | 1,066,778                      | 1,067,000                      | 1,067,000                      |
| O&M<br>Dredging Volume<br>(3 yrs during<br>expansion)         | 3,198,896                      | 3,198,896                      | 3,199,761                      | 3,199,761                      | 3,200,213                      | 3,200,213                      | 3,200,333                      | 3,200,333                      | 3,201,000                      | 3,201,000                      |
| 2017 Capacity<br>(after expansion<br>new work and<br>O&M)     | 47,447,399                     | 47,974,155                     | 45,467,068                     | 46,132,447                     | 43,362,012                     | 44,174,745                     | 41,125,738                     | 42,095,010                     | 38,821,374                     | 39,951,951                     |
| Years Remaining<br>until<br>Capacity is<br>Exceeded           | 44                             | 48                             | 43                             | 47                             | 41                             | 45                             | 39                             | 42                             | 36                             | 40                             |

## 12.0 OPERATION & MAINTENANCE IMPACTS

SHEP analysis includes an examination of the possible impacts to the USACE Operations and Maintenance (O&M) Program. A detailed report of these findings titled *Savannah Harbor Expansion Project Impacts to O&M* is included in the Engineering Investigation Supplemental Materials. The annual impacts to the program include the following:

- Increased dredging costs for the Inner Harbor, Bar Channel, and Mitigation Areas
- O&M costs for the NSBL&D fish passage structure
- O&M costs for the Oxygen injection system
- Long term monitoring
- Curation costs for the CSS *Georgia* (removal of the CSS *Georgia* from the project area will be accomplished with SHEP construction funds, and the cost will be included in the project B/C ratio determination)

### 12.1 MITIGATION – DISSOLVED OXYGEN SYSTEM

Impacts to D.O. throughout the Savannah River Estuary due to SHEP were determined through studies outlined in Section 7.0 Hydrodynamic Modeling of this report and the EIS. These studies evaluated the impacts to D.O. in the Harbor due to SHEP and outlined a plan for mitigation of these impacts. Mitigation for these impacts will involve construction of a dissolved oxygen injection system using Speece Cone technology and on-site Oxygen generation. Once construction of this system is complete, it will be operated and maintained by the USACE, Savannah District.

The annual impacts to O&M by the Dissolved Oxygen Injection System are for upkeep of the landside facilities to house the system and for the operating costs to produce the oxygen and are shown by project depth in **Table 12.1-1** below. Also included in the annual O&M costs are the replacement costs for the Speece cone and intake and discharge lines at 40 year intervals; and replacement of the oxygen flow control, oxygen generator, and side stream pump at 20 year intervals.

The expected annual costs for operating and maintaining the D.O. injection system is based on continued operation for a period up to 180 days per year (May - October). The operational costs are expected to be uniform throughout that 180-day period. **Table 12.1-1** shows the associated costs for the mitigation feature.

**Table 12.1-1: Dissolved Oxygen Injection System Expected Annual Operation and Maintenance Costs**

| Project Depth Alternative<br>(ft below MLLW) | Expected Annual<br>O&M Costs |
|----------------------------------------------|------------------------------|
| 44                                           | \$1,110,000                  |
| 45                                           | \$908,500                    |
| 46                                           | \$1,110,000                  |
| 47                                           | \$1,210,400                  |
| 48                                           | \$1,311,000                  |

## 12.2 INNER HARBOR MAINTENANCE

**Current Dredging Market** – Past dredging work in Savannah and Brunswick Harbors was performed by as many as 4 different small business contractors; however, current plans advertise this work in the unrestricted category, since the competitive field of dredging contractors capable of dredging Savannah Harbor has been reduced. Currently, we are working near the limit of the small dredges (18 inch cutterhead.) capability due to the depth of the channel, the length of the dredge pipeline to the dredged material containment areas, and the height of containment areas. It is the District's contention that using larger dredges will be more cost effective (22 to 30 inch cutterhead) to perform this work. Starting in FY08, Savannah Harbor maintenance dredging work has been advertised in the unrestricted category.

**Current Project Conditions** – In order to project shoaling conditions after the Savannah Harbor Expansion project is completed, CESAW-EN conducted an investigation of historical Inner Harbor shoaling rates and dredging volumes per river reach both With and Without the project (harbor deepening and mitigation features) in existence. With authorization and implementation of the Savannah Harbor Expansion Project the Sediment Basin would be filled. The filling of the Sediment Basin is a critical feature in mitigation planning for the Savannah Harbor Expansion Project as it restricts further upstream saltwater incursion.

**Mitigation Feature Impacts & Post-Project Conditions** – The selected mitigation plan as depicted in includes, among other things, demolition of the tidegate structure, removal of the northern and southern earthen abutments and construction of a sill across the throat of the Sediment Basin which will permit the Basin to fill with sediment to pre-harbor improvement conditions, thus reducing impacts to wetlands in the Back River by creating a partial barrier to saltwater intrusion up that river.

The end result of this mitigation action will be a return of the Inner Harbor shoaling regime to Pre-tidegate conditions, which is discussed in greater detail in Section 10.0. **Figure 12.2-1** below illustrates how the shoaling distribution in the harbor changes with and without operation of the Sediment Control Works. The green area in **Figure 12.2-1** represents the inner harbor shoaling patterns since the decommissioning of the tidegate. The shoaling pattern shown in blue represents the inner harbor prior to constructing the tidegate.

Figure 12.2-1: Annual Historic Dredging Volumes

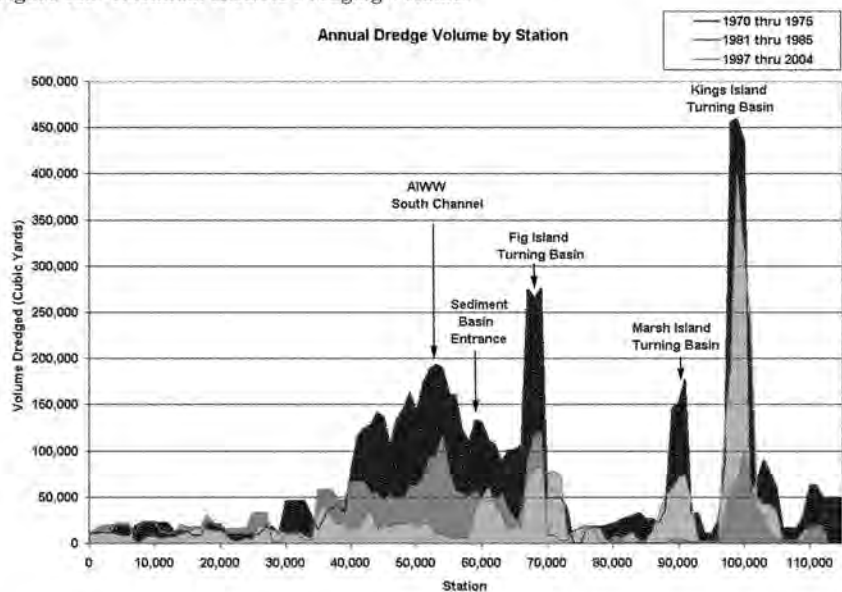


Table 12.2-1 compares historic average annual dredging quantities and costs for the middle harbor (Station 24+000 through Station 70+000) to projected quantities using the same removal costs. The total volume of sediment removed in the inner harbor is not expected to change with a harbor deepening, but the location of the shoaling will be different. Future maintenance costs for the middle harbor, using recent average annual costs, will be almost two and a half times greater than existing costs based purely on a different distribution of the sediments. This is a direct result of having to dredge 1,932,000 cubic yards of materials from the channel instead of the Sediment Basin. The difference in cost results from the increased pumping distances to disposal areas and the loss of dredge efficiency due to reduced effective working time caused by passing vessels. There is also a loss of dredge efficiency related to the decreased dredging bank height in the channel (6-8 feet) as compared to 16-20 feet in the Sediment Basin. It should also be noted that if this area experiences periods of above normal precipitation costs could rise considerably.

**Table 12.2-1: Historic vs. Projected Sediment Volumes and Associated Costs**

| Stations     | Historic Channel O&M Volume with Sediment Basin | Historic Cost | Projected Channel O&M Volume without Sediment Basin | Cost        |
|--------------|-------------------------------------------------|---------------|-----------------------------------------------------|-------------|
| 24 to 40+000 | 328,000                                         | \$734,720     | 364,000                                             | \$815,360   |
| 40 to 50+000 | 260,000                                         | \$624,000     | 900,000                                             | \$2,160,000 |
| 50 to 70+000 | 820,000                                         | \$2,328,800   | 2,076,000                                           | \$5,895,840 |
| Total        | 1,408,000                                       | \$3,687,520   | 3,340,000                                           | \$8,871,200 |

The mitigation plan also includes deepening of McCoy's Cut and construction of a freshwater diversion structure on the Savannah River near the cut. These features will facilitate more freshwater flow into the Back and Middle Rivers adjacent to the Savannah National Wildlife Refuge. Maintaining the deepened reaches on Back and Middle Rivers is expected to include dredging approximately 70,763 cubic yards of material from this area every 10 years. Dredging costs for this effort are estimated to be \$1,415,000 every 10 years (\$141,500/year or \$7,075,000 for the 50-year life of the project). These mitigation features are consistent for all project depths, with the exception of deepening McCoy's Cut which is not included in the 44 ft depth alternative, and costs are not expected to vary by depth.

Maintenance of the fish passage structure at NSBL&D will require clearing and snagging every 2-3 years to maintain the flow, which is estimated at \$50,000/year.

**Current Concerns** – The major concerns related to maintenance of the authorized depth in the inner harbor after SHEP are 1) the limited availability of O&M funds, 2) the anticipated change in shoaling locations, 3) the availability of a dredge capable of dredging in the Savannah Harbor, and 4) the limited dredging time due to environmental windows. The historical solution to all four of these concerns has been the systematic application of advance maintenance in the harbor and concentrating dredging on the middle half of the channel. Since the 1970's, the Savannah District has justified the need to dredge below the congressionally authorized depth in nearly every reach of the harbor for the purpose of maintaining the authorized depth for shipping, necessitated by the rapidity with which the channel shoals accrete. Through a series of justifications and approvals based on shoaling and dredging records, the District proved that advance maintenance was both an environmentally and economically sound method of providing navigable depths.

**Recommendations** – Advance maintenance for the currently authorized project is shown in **Table 12.2-2**. For the SHEP recommended depth alternative and mitigation plan, this table also shows three locations (identified by an asterisk and highlighted in yellow) where additional material is expected to accumulate and additional advance maintenance may be needed in order to maintain existing levels of service. These three locations were identified during the sedimentation analysis for the SHEP; details of this analysis can be found in Section 10.0 of this report. This need is based on the assumption that the same level of dredge plant will be required.

These predicted changes may require changes to the advance maintenance program. However, the future shoaling cannot be determined precisely by modeling. By allowing the harbor to stabilize after SHEP construction, the shoaling patterns would likely be established and at that point the District may determine that some adjustments to the advance maintenance program would be beneficial. If that determination is made, the District will seek approval to implement modifications to the program through the normal business process which would include an economic justification and environmental assessment.

**Table 12.2-2: Advance Maintenance for Existing and SHEP Recommended Project Depths**

| Stations                   | Currently Authorized Project             |                          |                                            | SHEP Project                       |
|----------------------------|------------------------------------------|--------------------------|--------------------------------------------|------------------------------------|
|                            | Authorized Project Depth (ft below MLLW) | Advance Maintenance (ft) | Maintenance Dredging Depth (ft below MLLW) | Estimated Advance Maintenance (ft) |
| -98+600 to -60+000**       | Not applicable                           |                          |                                            | 0                                  |
| -60+000 to -14+000         | 44                                       | 0                        | 44                                         | 0                                  |
| -14+000 to 24+000          | 42                                       | 2                        | 44                                         | 2                                  |
| 24+000 to 35+000           | 42                                       | 4                        | 46                                         | 4                                  |
| 35+000 to 37+000           | 42                                       | 6                        | 48                                         | 6                                  |
| 37+000 to 50+500           | 42                                       | 4                        | 46                                         | 4                                  |
| 50+500 to 52+750           | 42                                       | 4                        | 46                                         | 6 *                                |
| 52+750 to 54+000           | 42                                       | 4                        | 46                                         | 4                                  |
| 54+000 to 60+250           | 42                                       | 4                        | 46                                         | 8 *                                |
| 60+250 to 66+750           | 42                                       | 4                        | 46                                         | 4                                  |
| 66+750 to 70+000           | 42                                       | 4                        | 46                                         | 6 *                                |
| 70+000 to 102+000          | 42                                       | 2                        | 44                                         | 2                                  |
| 102+000 to 103+000         | 42                                       | 0                        | 42                                         | 0                                  |
| Kings Island Turning Basin | 42                                       | 8                        | 50                                         | 8                                  |

\* Estimated changes in advance maintenance program due to SHEP recommended depth alternative and mitigation plan to maintain existing levels of service.

\*\*Station -98+600 is the extended channel stationing for the 48 ft project depth. Channel stationing for the 47 ft project depth across the ocean bar terminates at Station -97+680.

### 12.2.1 Advance Maintenance Justification

The current advance maintenance program for the Savannah Harbor Navigation Project was developed in response to changes in the harbor after the 1992 Harbor Deepening Project (from 38 feet to 42 feet below MLLW) and the removal of the tidegate from operation in March 1991. The program is based on the shoaling patterns observed since completion of the 1992 Harbor Deepening Project and the discontinued operation of the tidegate. The program covers the entire length of the harbor and was developed to provide a more efficient, cost effective, and environmentally acceptable maintenance program for the harbor. The program does not provide additional navigational depth to the navigation channel since shoaling will continue to occur above authorized project depth before periodic maintenance dredging commences.

The current advance maintenance program for Savannah Harbor was authorized in the Deepening Project in accordance with House Document 102-394, 102d Congress, 2<sup>nd</sup> Session. Implementation of the advance maintenance program allowed the District to maximize our use of the Dredged Material Management Plan (DMMP) (April 2003) with the 3-year rotation plan for the dredged material containment areas (DMCA). The 2003 DMMP in conjunction with the LTMS (1996), projected an average annual cost savings of \$1.1 million per year and an extension of DMCA system life from 5 to 20 years upon implementation. Additionally, more efficient dredging procedures allows full use of one pipeline dredge on an annual basis for the Inner Harbor dredging contract. Currently, one dredge is used, but even with the current advance maintenance program, three to four dredge movements to cut down on fast rising shoals are required. Savings associated with each movement of a dredge during the contract are estimated to be \$30,000 for the actual move and 2 days of dredging lost while moving the dredge. Performing advance maintenance saves a minimum of four dredge movements during each contract. Therefore, a cost avoidance of least \$120,000 and 8 days lost production per year are realized. Under the program, about 48% of the harbor navigation channel will require advance maintenance of at least 2-ft, 19% will require advance maintenance of at least 4 ft, and 8% will require advance maintenance of at least 6 ft. Two of the seven harbor turning basins, Fig Island and Kings Island, will require advance maintenance of 4 ft and 8 ft, respectively.

Savannah District's goal is to dredge the navigation channel on an annual basis with a minimum cost and maximum efficiency of operation of both dredging and containment area operation. An annual cycle will provide the ability to better coordinate our actions with the local assurer and better fulfill our environmental commitments. The current advance maintenance program is represented in **Table 12.2.1-1**. Please note, currently, advance maintenance is authorized in two of the five turning basins. See **Table 12.2.1-2**. **Tables 12.2.1-2** and **12.2.1-3** describe the locations of the turning basins and the DMCA's respectively.



**Table 12.2.1-1: Currently Authorized Advance Maintenance Depth by Station**

| <b>Station</b>                | <b>Authorized Depth (ft below MLLW)</b> | <b>Authorized Advance Maintenance (ft)</b> | <b>Allowable Over-depth (ft)</b> | <b>Maximum Sediment Removal Depth (ft below MLLW)</b> |
|-------------------------------|-----------------------------------------|--------------------------------------------|----------------------------------|-------------------------------------------------------|
| 112+500 to 105+500            | 30                                      | 2                                          | 2                                | 34                                                    |
| 105+500 to 103+000            | 36                                      | 2                                          | 2                                | 40                                                    |
| 103+000 to 102+000            | 42                                      | 0                                          | 2                                | 44                                                    |
| 102+000 to 70+000             | 42                                      | 2                                          | 2                                | 46                                                    |
| 70+000 to 37+000              | 42                                      | 4                                          | 2                                | 48                                                    |
| 37+000 to 35+000              | 42                                      | 6                                          | 2                                | 50                                                    |
| 35+000 to 24+000              | 42                                      | 4                                          | 2                                | 48                                                    |
| 24+000 to 0+000               | 42                                      | 2                                          | 2                                | 46                                                    |
| 0+000 to -14+000              | 42                                      | 2                                          | 2                                | 46                                                    |
| -14+000 to -60+000            | 44                                      | 0                                          | 2                                | 46                                                    |
| Jones/Oysterbed Turning Basin | 40                                      | 0                                          | 2                                | 42                                                    |
| Fig Island Turning Basin      | 34                                      | 4                                          | 2                                | 40                                                    |
| Marsh Island Turning Basin    | 34                                      | 0                                          | 2                                | 36                                                    |
| Kings Island Turning Basin    | 42                                      | 8                                          | 2                                | 52                                                    |
| Argyle Island Turning Basin   | 30                                      | 0                                          | 2                                | 32                                                    |
| Port Wentworth Turning Basin  | 30                                      | 0                                          | 2                                | 32                                                    |

**Table 12.2.1- 2: Specifications & Locations of Turning Basins**

| Turning Basin          | Length (ft) | Width (ft) | Maintenance Depth* (ft below MLLW) | River Mile | Station            |
|------------------------|-------------|------------|------------------------------------|------------|--------------------|
| Port Wentworth         | 600         | 600        | 30                                 | 20.9       | 111+363 to 109+757 |
| Argyle Island          | 600         | 600        | 30                                 | 19.6       | 104+185 to 103+085 |
| Kings Island           | 1,600       | 1,500      | 50                                 | 18.8       | 101+298 to 97+750  |
| Marsh Island           | 900         | 1000       | 34                                 | 17.1       | 91+610 to 89+485   |
| Fig Island             | 1500        | 1000       | 38                                 | 13.0       | 69+740 to 67+386   |
| Jones/Oysterbed Island | 1050        | 1200       | 40                                 | 0.7        | 4+395 to 2+345     |

\*Maintenance Depth excludes Allowable Over-Depth.

**Table 12.2.1-3: Locations of Dredged Material Containment Areas (DMCA)**

| DMCA            | Station*            | DMCA acreage |
|-----------------|---------------------|--------------|
| 1N              | 107+500 to 112+500  | 130          |
| 2A              | 93+000 to 103+000   | 240          |
| 12A             | 6+000BR to 10+500BR | 1040         |
| 13A             | 47+800 to 6+600BR   | 1307         |
| 13B             | 43+000 to 47+000    | 525          |
| 14A             | 37+000 to 47+000    | 647          |
| 14B             | 28+000 to 37+000    | 703          |
| Jones/Oysterbed | 10+000 to 27+000    | 803          |

\* Back River Channel Station

Advance maintenance dredging is authorized in Savannah Harbor to efficiently maintain the required projects depths. The importance of advance maintenance in a rapidly shoaling, silty harbor such as Savannah Harbor cannot be overstated. Given the lack of sufficient contractor equipment, environmental windows and limited funding, advance maintenance is a necessity. For example, prior to 1996, the Kings Island Turning Basin without 8 feet of advance maintenance routinely shoaled to 34 feet in a four month period causing major problems for pilots turning vessels. The District simply could not dredge the basin and the channel in a timely manner because of the striped bass window and dissolved oxygen requirements. Since the advance maintenance was instituted, we have been able to insure turning basin depths for longer periods of time and have not faced the crisis modes of the years prior to 1996.

Maintaining harbor channel project depth at the level of service required by the pilots and the USCG without advance maintenance would be impossible due to the sedimentation rate in the harbor. Providing project depth would require increased funds and the need for additional dredging plant. Even with these assets, the existing environmental windows would prevent dredging to the degree necessary to maintain depths adequate for navigation.

The Savannah Harbor annual maintenance dredging budget has increased from approximately \$8.5 million in 1990-91 to \$13.9 million in 2000 and has remained at this level to this date. Historical dredging records indicate that shoaling rates in the harbor have not changed, but the locations of shoals since the tidegate decommissioning have shifted locations to the upper harbor where disposal area capacity is negligible thus requiring longer pumping distances and increased costs. Loss of advance maintenance would exacerbate this problem due to the requisite number of dredge re-mobilizations.

In **Figure 12.2.1-1**, developed for the SHEP sedimentation analysis, the area in blue represents Savannah Harbor shoaling patterns prior to the construction of the tidegate (1970 – 1975), the area in red represents Savannah Harbor shoaling patterns during the operation of the tidegate (1981 – 1985), and the area in light green represents Savannah Harbor shoaling patterns since the tidegate was taken out of operation in March 1991 (1997 – 2004). Please note that the current (1997 – 2004) shoaling patterns are beginning to revert back to the shoaling patterns prior to the construction of the tidegate (blue color). Also note that the areas highlighted in yellow on **Table 12.2.1-4** need to be dredged on a 6-month cycle. These areas conform closely with those areas in blue (pre-tidegate shoaling patterns). This is an indication that the current approved advance maintenance program needs to be preserved if we are going to keep the harbor operating efficiently.

**Figure 12.2.1-1: Annual Historic Dredging Volumes**

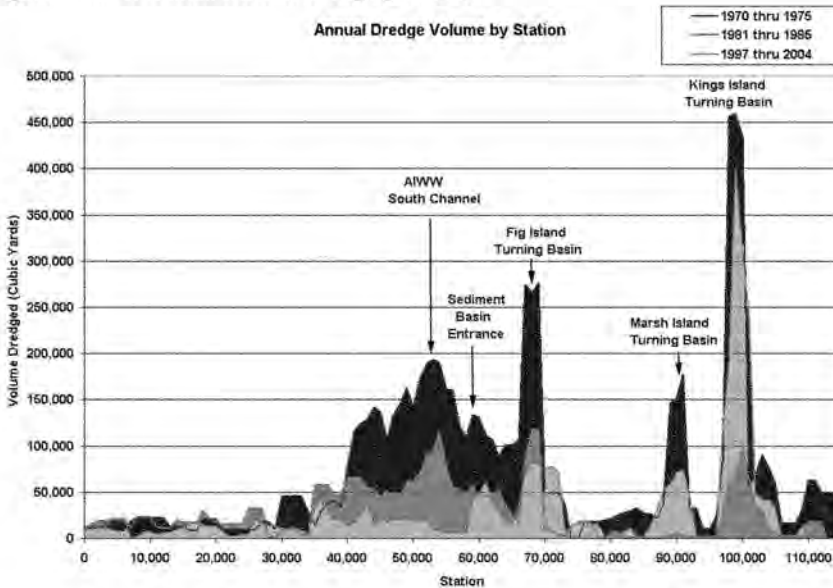


Table 12.2.1-4: Shoaling Average (cy) by Station for 2008 - 2009

| Station | Shoaling Volume (cy) | Station | Shoaling Volume (cy) | Station | Shoaling Volume (cy) |
|---------|----------------------|---------|----------------------|---------|----------------------|
| 0       | 11,866               | 38+000  | 24,392               | 76+000  | 23,825               |
| 1+000   | 11,866               | 39+000  | 24,867               | 77+000  | 18,418               |
| 2+000   | 13,946               | 40+000  | 15,157               | 78+000  | 18,418               |
| 3+000   | 12,266               | 41+000  | 21,054               | 79+000  | 3,746                |
| 4+000   | 25,921               | 42+000  | 32,835               | 80+000  | 2,959                |
| 5+000   | 25,921               | 43+000  | 42,262               | 81+000  | 2,959                |
| 6+000   | 26,184               | 44+000  | 17,155               | 82+000  | 9,995                |
| 7+000   | 1,026                | 45+000  | 25,345               | 83+000  | 13,606               |
| 8+000   | 2,445                | 46+000  | 20,211               | 84+000  | 1,586                |
| 9+000   | 8,337                | 47+000  | 25,524               | 85+000  | 1,586                |
| 10+000  | 8,160                | 48+000  | 25,158               | 86+000  | 16,780               |
| 11+000  | 5,337                | 49+000  | 26,665               | 87+000  | 36,899               |
| 12+000  | 6,781                | 50+000  | 22,060               | 88+000  | 63,586               |
| 13+000  | 6,888                | 51+000  | 25,242               | 89+000  | 72,272               |
| 14+000  | 11,533               | 52+000  | 25,242               | 90+000  | 86,497               |
| 15+000  | 14,790               | 53+000  | 10,667               | 91+000  | 91,420               |
| 16+000  | 18,308               | 54+000  | 11,369               | 92+000  | 54,434               |
| 17+000  | 18,756               | 55+000  | 6,245                | 93+000  | 2,050                |
| 18+000  | 18,764               | 56+000  | 5,751                | 94+000  | 2,050                |
| 19+000  | 15,669               | 57+000  | 6,683                | 95+000  | 2,050                |
| 20+000  | 15,186               | 58+000  | 6,011                | 96+000  | 1,693                |
| 21+000  | 9,740                | 59+000  | 46,565               | 97+000  | 142,429              |
| 22+000  | 2,516                | 60+000  | 60,347               | 98+000  | 232,556              |
| 23+000  | 1,858                | 61+000  | 74,865               | 99+000  | 489,662              |
| 24+000  | 6,023                | 62+000  | 47,994               | 100+000 | 378,601              |
| 25+000  | 4,572                | 63+000  | 37,084               | 101+000 | 293,983              |
| 26+000  | 24,413               | 64+000  | 18,925               | 102+000 | 60,257               |
| 27+000  | 19,840               | 65+000  | 18,679               | 103+000 | 50,618               |
| 28+000  | 16,054               | 66+000  | 42,012               | 104+000 | 51,599               |
| 29+000  | 16,521               | 67+000  | 85,725               | 105+000 | 40,057               |
| 30+000  | 12,758               | 68+000  | 99,524               | 106+000 | 2,684                |
| 31+000  | 13,158               | 69+000  | 99,524               | 107+000 | 2,684                |
| 32+000  | 13,158               | 70+000  | 91,460               | 108+000 | 2,684                |
| 33+000  | 10,511               | 71+000  | 95,409               | 109+000 | 13,305               |
| 34+000  | 6,595                | 72+000  | 87,680               | 110+000 | 21,336               |
| 35+000  | 42,128               | 73+000  | 9,810                | 111+000 | 21,336               |
| 36+000  | 49,315               | 74+000  | 14,794               | 112+000 | 22,334               |
| 37+000  | 34,386               | 75+000  | 21,570               |         |                      |

Note: Stations highlighted in yellow require dredging twice a year.

### 12.2.1.1 Advance Maintenance Justification by Station

#### Station 112+500 to Station 103+000

Advance maintenance in this segment is currently 2 feet which was justified after the 1992 Deepening Project. Sediments in this segment were originally deposited in DMCA 2A, but since this DMCA has limited storage capacity, the sediments are now pumped to DMCAs 12A or 13A (an additional two booster pumps) depending on the rotation schedule. The objective is to remove the predominantly sandy materials before they travel to Kings Island Turning Basin (KITB) and further downstream to an area where sand waves, which are a hazard to navigation due to their density, form. Relocating the sand to DMCA 12A (or 13A) will maximize the life of DMCA 2A and will help minimize future sand waves causing problems with harbor operations between Station 79+600 and KITB.

#### Kings Island Turning Basin (Station 102+000 to 97+000) and Adjacent Channel

Initial indications are that the current approved advance maintenance (8 feet), while somewhat effective, may need to be increased since the District is still dredging the basin on a 6-month rotation rather than a yearly rotation. Current advance maintenance has proved effective in extending the time between dredging intervals to a limited extent and providing a safer area in which to turn ships, but additional advance maintenance may be requested in the future. This basin is the only turning basin capable of handling the post-Panamax design vessel. The pilots must use the upper end of the basin when turning to maintain safe maneuverability while turning the ship in a strong ebb tide. Biennial dredging reduces the time that large military and commercial ships risk damage due to grounding while using the basin.

The current requirement of a 6-month dredging cycle even with the 8-foot of advance maintenance is costly. With DMCA 2A no longer available, we are required to use DMCAs 12A or 13A depending on the rotation. The use of DMCA 12A or 13A requires two booster pumps which triples the dredging costs. While the 8 feet of advance maintenance was estimated to give us a yearly dredging cycle, the result has been a 6 month cycle which has been far more costly. This, however, may be more due to the fish window and the efficiency of the dredge rather than the number of times we could dredge the basin.

Future cost savings would result from reducing the costs associated with having to move a dredge on station the second time during a contract and the elimination of one dredging cycle using two booster pumps.

#### Station 97+000 to 79+600

The existing two feet of advance maintenance must be maintained, and an additional 4 feet needs to be approved on the south side of the channel for Station 86+000 to 92+000 (Marsh Island Turning Basin and below). This channel segment is an area of sand wave formation. The advance maintenance needs to be approved to minimize the impact of sand waves. Even though sand waves are not large formations, the waves are a hazard to navigation due to their density. Measurement and dredging of the wave is difficult because the waves are perpendicular to the channel. Since the 1992 Deepening Project, we have dredged the sand waves on an annual basis.

Part of the advance maintenance has been dredged, and indications are that the sand waves are peaking below the authorized channel depth except on the south side of the channel between Station 86+000 and 92+000. Shoaling between Station 86+000 and 92+000 requires additional advance maintenance. We expect minimal sand waves above the authorized channel dimensions in the future. However, some sand waves may continue to exist and must be removed due to the hazard to navigation that they pose. DMCA's 12A and 13A are available for placement of material from this channel segment.

#### Station 79+600 to 73+000

We have dredged the channel segment on an annual basis since the 1992 deepening project. We are currently experiencing transient shoaling in the channel segment during our ongoing maintenance dredging contract and cannot estimate a shoaling rate for the segment. We believe the current two feet of advance maintenance will be sufficient to prevent the transient shoals from becoming an obstruction to navigation. Cost savings would be the costs associated with moving a dredge on station for the second time during the contract.

#### Station 73+000 to 70+000

The two feet already in place is fine, but we may need to request additional advance maintenance (five additional feet) in order to get back to a yearly cycle rather than the 6-month cycle we are in now. Shoaling is occurring on the north side of the channel at a rate of two feet per month requiring us to dredge the segment at about 6-months interval. The cost savings for dredging the segment on an annual basis would result from the lack of need to have a dredge on standby to dredge the shoal and the costs associated with moving a dredge on station the second time during the contract.

#### Fig Island Turning Basin (Station 69+740 to 67+386)

The four feet of advance maintenance currently approved in the basin should be maintained. The basin is located adjacent to a heavily shoaling channel segment that needs to be dredged on a 6-month cycle. The material removed from the basin also helps increase the time between dredging cycles in the channel.

#### Station 70+000 to 59+000

We currently have four feet of advance maintenance in this segment of the channel which was approved in the 1992 Deepening Project. Shoaling rates in the channel are up to a foot per month. We are dredging the segment on a 6-month cycle. Cost savings for an annual dredging cycle would be the costs associated with moving a dredge on station the second time during the contract.

#### Station 59+000 to 37+000

The four feet of advance maintenance currently approved should be maintained. Shoaling is continuing at a rate that the advance maintenance is necessary.

Station 37+000 to 35+000

Currently, six feet of advance maintenance has been approved for the channel segment. The channel segment is shoaling at a rate of a foot per month. Cost savings would be the costs associated with moving a dredge on station the time during the contract.

Station 35+000 to 24+000

The four feet of advance maintenance currently approved should be maintained. Shoaling is continuing at a rate that justifies advance maintenance.

Station 24+000 to 0+000

The two feet of advance maintenance currently approved should be maintained. The unit cost of dredging the channel segment is much higher (\$6.40/CY vs. \$5.20/CY) than the rest of the Inner Harbor Channel due to the type of material (sand) in the segment. We need the advance maintenance to give us flexibility in scheduling our dredging of the channel segment to a time we have funds available from reduced costs in another channel segment. We expect the reduced costs will result from the rotational use of the containment areas (Jones/Oysterbed versus 14B) and the shortened pumping distances that occur during the rotational cycle.

Station 0+000 to -14+000

We currently have two feet of advance maintenance for this channel segment which is located in the Entrance Channel and can only be dredged by a hopper dredge during December through March. The shoal in the channel segment develops across the channel to a height of two feet above project depth in less than the yearly maintenance cycle. Hopper dredging at more frequent intervals is not allowed throughout the year due to environmental constraints and use of a cutterhead dredge would require a seagoing cutterhead dredge. Mobilization costs for a seagoing cutterhead dredge could be expected to be in excess of \$1,000,000 and thus be prohibitive.

Station 14+000 to -60+000

Current shoaling rates indicate no advance maintenance is required at the present time.

With the construction of the tidegate, the shoals moved out of the turning basins in the upper harbor, Kings Island, Marsh Island, and Fig Island; and City Front into the newly constructed Sediment Basin. With the removal of the tidegate and the filling in of the Sediment basin, the shoals are beginning to return to the turning basins and the city front. These shoaling areas are highlighted in yellow in **Table 12.2.1-4** shown previously. This is a strong indication that the currently requested advance maintenance in those areas may have to be increased even more for future dredging operations.

### 12.2.1.2 Advance Maintenance Recommendation

Shoaling patterns have changed as a result of Harbor widening and deepening, removal of the tidegate from operation, and low flows from the Savannah River Below Augusta (SRBA) as a result of long-period drought conditions. Future dredging without advance maintenance would require increased O&M funding due to the inefficiencies in dredging – more dredges would be required with an

increased number of contracts, decreased dredging efficiency, and increased mobilizations. There may not be sufficient dredges available to meet the demands of the channel without advance maintenance as multiple dredges will be required to dredge many areas of the channel at once. Based on the District's experience with dredging the harbor during the pre and post tidewater operational period, the advance maintenance program is absolutely vital to the provision of a safe, reliable, and cost effective channel.

### 12.3 ENTRANCE CHANNEL MAINTENANCE

**Current Annual Maintenance Cycle** – Maintenance dredging is presently performed on an annual basis. The current annual maintenance dredging costs for the entrance channel are shown in **Table 12.3-1**. This annual dredging process entails hopper dredges removing the dredged material from the entrance channel and placing it in the ocean dredged material disposal site (ODMDS). SHEP will require the re-alignment and extension of the entrance channel from Station -60+000 to Station -97+680, which will result in an increase in annual maintenance. See **Table 12.3-2**.

**Coastal Zone Management Act (CZM)** – Construction of the proposed project would be fully consistent with both Georgia and South Carolina's coastal zone management programs. The new work sediments associated with dredging the entrance channel will be placed in the ODMDS and an existing upland CDF.

Due to their cost effectiveness, hopper dredges are expected to be the primary equipment used to maintain depths in the entrance channel. Those dredges would generally deposit maintenance sediments in the ODMDS, Site 2 or Site 3 because the other nearshore placement areas are too shallow for direct access to hopper dredges. This material could be placed in the nearshore placement areas if a non-Federal interest paid the incremental cost that would be required.



**Table 12.3-1: Current Entrance Channel Annual Maintenance Costs**

| <b>Stations</b>    | <b>Disposal Site</b> | <b>O&amp;M Dredge Costs \$/cy (Oct 2007 Price Level)</b> | <b>Project Annual Maintenance Volume (cy)</b> | <b>Projected O&amp;M Costs</b> |
|--------------------|----------------------|----------------------------------------------------------|-----------------------------------------------|--------------------------------|
| -85+000 to -57+000 | ODMDS                | \$4.35                                                   | 10,000                                        | \$43,500                       |
| -57+000 to -53+000 | ODMDS                | \$4.35                                                   | 3,000                                         | \$13,050                       |
| -53+000 to -40+000 | ODMDS                | \$4.35                                                   | 54,000                                        | \$234,900                      |
| -40+000 to -30+000 | ODMDS                | \$4.35                                                   | 325,000                                       | \$1,413,750                    |
| -30+000 to -20+000 | ODMDS                | \$4.35                                                   | 281,000                                       | \$1,222,350                    |
| -20+000 to -10+000 | ODMDS                | \$4.35                                                   | 163,000                                       | \$709,050                      |
| -10+000 to 0+000   | ODMDS                | \$4.35                                                   | 155,000                                       | \$674,250                      |
| 0+000 to 4+000     | ODMDS                | \$4.35                                                   | 76,000                                        | \$330,600                      |
| <b>TOTAL</b>       |                      |                                                          | <b>1,067,000</b>                              | <b>\$4,641,450</b>             |
|                    |                      |                                                          |                                               |                                |
|                    |                      |                                                          | Mob & Demob                                   | \$690,000                      |
|                    |                      |                                                          | Multiple Mobs                                 | \$40,000                       |
|                    |                      |                                                          | Total Mob & Demob                             | \$730,000                      |
|                    |                      |                                                          | PED                                           | \$40,000                       |
|                    |                      |                                                          | S&A                                           | \$100,000                      |
|                    |                      |                                                          |                                               |                                |
|                    |                      |                                                          | <b>TOTAL</b>                                  | <b>\$5,511,450</b>             |

**Table 12.3-2: Projected SHEP Entrance Channel Annual Maintenance Costs**

| Stations           | Disposal Site | O&M Dredge Costs \$/cy Oct 2007 Price Level | Project Annual Maintenance Volume (cy) | Projected O&M Costs |
|--------------------|---------------|---------------------------------------------|----------------------------------------|---------------------|
| -98+600 to -57+000 | ODMDS         | \$4.35                                      | 21,310                                 | \$92,699            |
| -57+000 to -53+000 | ODMDS         | \$4.35                                      | 3,000                                  | \$13,050            |
| -53+000 to -40+000 | ODMDS         | \$4.35                                      | 54,000                                 | \$234,900           |
| -40+000 to -30+000 | ODMDS         | \$4.35                                      | 325,000                                | \$1,413,750         |
| -30+000 to -20+000 | ODMDS         | \$4.35                                      | 281,000                                | \$1,222,350         |
| -20+000 to -10+000 | ODMDS         | \$4.35                                      | 163,000                                | \$709,050           |
| -10+000 to 0+000   | ODMDS         | \$4.35                                      | 155,000                                | \$674,250           |
| 0+000 to 4+000     | ODMDS         | \$4.35                                      | 76,000                                 | \$330,600           |
| TOTAL              |               |                                             | 1,078,310                              | \$4,690,649         |
|                    |               |                                             |                                        |                     |
|                    |               |                                             | Mob & Demob                            | \$690,000           |
|                    |               |                                             | Multiple Mobs                          | \$40,000            |
|                    |               |                                             | Total Mob & Demob                      | \$730,000           |
|                    |               |                                             | PED                                    | \$40,000            |
|                    |               |                                             | S&A                                    | \$100,000           |
|                    |               |                                             |                                        |                     |
|                    |               |                                             | TOTAL                                  | \$5,560,649         |
|                    |               |                                             |                                        |                     |
|                    |               |                                             | Impact to O&M                          | \$49,199            |

## 12.4 SUMMARY OF OPERATION AND MAINTENANCE IMPACTS

Currently, Savannah District receives approximately \$13M for O&M dredging and maintenance of the upland disposal areas. This does not include funds for dike raising which are described in **Table 12.4-1**. Current practice is to conduct maintenance dredging of critical shoals to the limit of funding and to seek additional funding for the remainder of critical shoals and other shoals growing in the sides of the channel. However, under current conditions, with the sediment basin operational, if the entire channel prism were maintained the cost would be \$24,368,190 (current price levels) an increase of approximately \$11.4 million (59%) over the present O&M funding.

This information is based on a Sedimentation Analysis done for SHEP; details are in Section 10.0 of this report. The sill constructed at the throat of the Sediment Basin as a mitigation feature along with the discontinued practice of maintaining the Sediment Basin will cause it to fill. This will result in the sediment currently being captured in the Sediment Basin (~1,932,000 cy) being deposited in the navigation channel mainly in the range from Station 24+000 to Station 70+000. This will result in an increase of O&M dredging and maintenance costs to \$27,861,490 or an increase attributable to the project of \$3,493,300. Of this total, \$3,442,927 was attributed to the Inner Harbor while \$50,373 was attributed to the Bar Channel. See **Table 12.4-2**.

**Table 12.4-1: SHEP Annual Work Plan – Dike Raising Schedule**

| Year | Project                  | Total Estimated Costs | Federal Costs | Non-Federal Costs |
|------|--------------------------|-----------------------|---------------|-------------------|
| 2010 | 13A Dikes Raising        | \$3,078,880           | \$2,001,272   | \$1,077,608       |
|      | Dike Maintenance         | \$590,000             | \$560,000     | \$30,000          |
|      | Mosquito Control         | \$300,000             | \$300,000     | \$0               |
|      | Bird Island Construction | \$900,000             | \$600,000     | \$300,000         |
| 2011 | JOI Dike Raising         | \$11,950,000          | \$7,767,500   | \$4,182,500       |
|      | Dike Maintenance         | \$597,000             | \$567,000     | \$30,000          |
|      | Mosquito Control         | \$300,000             | \$300,000     | \$0               |
| 2012 | Dike Maintenance         | \$615,000             | \$615,000     | \$0               |
|      | Mosquito Control         | \$300,000             | \$300,000     | \$0               |
| 2013 | 12A Dike Raising         | \$9,000,000           | \$5,850,000   | \$3,150,000       |
|      | Dike Maintenance         | \$633,000             | \$633,000     | \$0               |
|      | Mosquito Control         | \$300,000             | \$300,000     | \$0               |
| 2014 | Dike Maintenance         | \$640,000             | \$640,000     | \$0               |
|      | Mosquito Control         | \$300,000             | \$300,000     | \$0               |
| 2015 | Dike Maintenance         | \$650,000             | \$650,000     | \$0               |
|      | Mosquito Control         | \$300,000             | \$300,000     | \$0               |

*\*The raising of dikes is coordinated with the rotation schedule of the CDFs which is included in the DMMP Annual Work Plan.*

**Table 12.4-2: Average Annual Current & Post SHEP Construction Harbor Maintenance Costs**

| Range                                           | O&M<br>Dredge<br>Costs<br>\$/cy | Current<br>Annual<br>Maintenance<br>Volume (cy) | Current<br>Annual<br>Maintenance<br>Costs | Projected<br>Annual<br>Maintenance<br>Volume (cy) | Projected<br>Annual<br>Maintenance<br>Costs |
|-------------------------------------------------|---------------------------------|-------------------------------------------------|-------------------------------------------|---------------------------------------------------|---------------------------------------------|
| -98+600 to -57+000*                             | \$4.35                          | 10,000                                          | \$43,500                                  | 21,580                                            | \$93,873                                    |
| -57+000 to -53+000                              | \$4.35                          | 3,000                                           | \$13,050                                  | 3,000                                             | \$13,050                                    |
| -53+000 to -40+000                              | \$4.35                          | 54,000                                          | \$234,900                                 | 54,000                                            | \$234,900                                   |
| -40+000 to -30+000                              | \$4.35                          | 325,000                                         | \$1,413,750                               | 325,000                                           | \$1,413,750                                 |
| -30+000 to -20+000                              | \$4.35                          | 281,000                                         | \$1,222,350                               | 281,000                                           | \$1,222,350                                 |
| -20+000 to -10+000                              | \$4.35                          | 163,000                                         | \$709,050                                 | 163,000                                           | \$709,050                                   |
| - 10+000 to 0+000                               | \$4.35                          | 155,000                                         | \$674,250                                 | 155,000                                           | \$674,250                                   |
| 0+000 to +4+000                                 | \$4.35                          | 76,000                                          | \$330,600                                 | 76,000                                            | \$330,600                                   |
| Entrance Channel Total                          |                                 | 1,067,000                                       | \$4,641,450                               | 1,078,580                                         | \$4,691,823                                 |
|                                                 |                                 |                                                 |                                           |                                                   |                                             |
| 4+000 to 24+000                                 | \$5.95                          | 225,000                                         | \$1,338,750                               | 225,000                                           | \$1,338,750                                 |
| 24+000 to 40+000                                | \$3.25                          | 328,000                                         | \$1,066,000                               | 364,000                                           | \$1,183,000                                 |
| 40+000 to 50+000                                | \$2.93                          | 260,000                                         | \$761,800                                 | 900,000                                           | \$2,637,000                                 |
| 50+000 to 70+000                                | \$2.80                          | 820,000                                         | \$2,296,000                               | 2,076,000                                         | \$5,812,800                                 |
| 70+000 to 79+000                                | \$2.40                          | 294,000                                         | \$705,600                                 | 294,000                                           | \$705,600                                   |
| 79+000 to 97+750                                | \$4.06                          | 605,000                                         | \$2,456,300                               | 605,000                                           | \$2,456,300                                 |
| 97+750 to 102+000                               | \$3.67                          | 1,456,000                                       | \$5,343,520                               | 1,456,000                                         | \$5,343,520                                 |
| 102+000 to 103+000                              | \$3.67                          | 51,000                                          | \$187,170                                 | 51,000                                            | \$187,170                                   |
| Inner Harbor Total                              |                                 | 4,039,000                                       | \$14,155,140                              | 5,971,000                                         | \$19,664,140                                |
|                                                 |                                 |                                                 |                                           |                                                   |                                             |
| Sediment Basin                                  | \$1.30                          | 1,932,000                                       | \$2,511,600                               | 0                                                 | \$0                                         |
| Projected Total without MOB & DEMOB             |                                 | 7,038,000                                       | \$21,308,190                              | 7,049,580                                         | \$24,355,963                                |
|                                                 |                                 |                                                 |                                           |                                                   |                                             |
| MOB & DEMOB Entrance Channel - One Hopper       |                                 |                                                 | \$690,000                                 |                                                   | \$690,000                                   |
| MOB & DEMOB Inner Harbor - Two Pipeline Dredges |                                 |                                                 | \$2,200,000                               |                                                   | \$2,200,000                                 |
| MULTIPLE MOBS                                   |                                 |                                                 | \$40,000                                  |                                                   | \$40,000                                    |
| MULTIPLE MOBS                                   |                                 |                                                 | \$40,000                                  |                                                   | \$40,000                                    |
| Total MOBS & DEMOBS                             |                                 |                                                 | \$2,970,000                               |                                                   | \$2,970,000                                 |
| PED                                             |                                 |                                                 | \$40,000                                  |                                                   | \$40,000                                    |
| S&A                                             |                                 |                                                 | \$50,000                                  |                                                   | \$50,000                                    |
|                                                 |                                 |                                                 |                                           |                                                   |                                             |
| Projected Total for All Costs                   |                                 |                                                 | \$24,368,190                              |                                                   | \$27,415,963                                |
|                                                 |                                 |                                                 | Projected Impacts to O&M                  |                                                   | \$3,047,773                                 |

\*Station -98+600 is the extended channel stationing for the 48 ft project depth. Channel stationing for the 47 ft project depth across the ocean bar terminates at Station -97+680.

Annual Savannah Harbor Expansion Project impacts to O&M are shown in **Table 12.4-3**, while **Table 12.4-4** contains the annual impacts to O&M for the NED Plan (47-ft) and the annual O&M project costs after SHEP construction. Cost sharing is 100-percent Federal above 45 feet and 50/50 Federal/non-Federal below 45 feet. Cost indexing was accomplished using EM 1110-2-1304 (March, 31 2000) *Civil Works Construction Cost Index System (CWCCIS)* (CWBS Code = 12 – Navigation Ports & Harbors).

**Table 12.4-3: Total Annual Impact to O&M**

| <b>44 ft Project Depth</b>   |                       |                       |                  |
|------------------------------|-----------------------|-----------------------|------------------|
|                              | Cost                  | Federal Cost          | Non-Federal Cost |
| Oxygen Injection System      | \$1,110,000.00        | \$1,110,000.00        | \$0.00           |
| Inner Harbor O&M Dredging    | \$2,672,080.00        | \$2,672,080.00        | \$0.00           |
| Channel Extension            | \$46,589.00           | \$46,589.00           | \$0.00           |
| Mitigation Features Dredging | \$114,000.00          | \$114,000.00          | \$0.00           |
| CSS Georgia Curation         | \$20,000.00           | \$20,000.00           | \$0.00           |
| Fish Passage O&M             | \$50,000.00           | \$50,000.00           | \$0.00           |
| Long Term Monitoring         | \$428,400.00          | \$428,400.00          | \$0.00           |
| <b>Total</b>                 | <b>\$4,441,069.00</b> | <b>\$4,441,069.00</b> | <b>\$0.00</b>    |
| <b>45 ft Project Depth</b>   |                       |                       |                  |
|                              | Cost                  | Federal Cost          | Non-Federal Cost |
| Oxygen Injection System      | \$908,500.00          | \$908,500.00          | \$0.00           |
| Inner Harbor O&M Dredging    | \$2,672,080.00        | \$2,672,080.00        | \$0.00           |
| Channel Extension            | \$48,155.00           | \$48,155.00           | \$0.00           |
| Mitigation Features Dredging | \$114,000.00          | \$114,000.00          | \$0.00           |
| CSS Georgia Curation         | \$20,000.00           | \$20,000.00           | \$0.00           |
| Fish Passage O&M             | \$50,000.00           | \$50,000.00           | \$0.00           |
| Long Term Monitoring         | \$428,400.00          | \$428,400.00          | \$0.00           |
| <b>Total</b>                 | <b>\$4,241,135.00</b> | <b>\$4,241,135.00</b> | <b>\$0.00</b>    |
| Continued on next page       |                       |                       |                  |

**Table 12.4-3: Total Annual Impact to O&M (continued)**

| <b>46 ft Project Depth</b>   |                       |                       |                     |
|------------------------------|-----------------------|-----------------------|---------------------|
|                              | Cost                  | Federal Cost          | Non-Federal Cost    |
| Oxygen Injection System      | \$1,110,000.00        | \$1,009,250.00        | \$100,750.00        |
| Inner Harbor O&M Dredging    | \$2,672,080.00        | \$2,672,080.00        | \$0.00              |
| Channel Extension            | \$48,938.00           | \$48,546.50           | \$391.50            |
| Mitigation Features Dredging | \$114,000.00          | \$114,000.00          | \$0.00              |
| CSS Georgia Curation         | \$20,000.00           | \$20,000.00           | \$0.00              |
| Fish Passage O&M             | \$50,000.00           | \$50,000.00           | \$0.00              |
| Long Term Monitoring         | \$428,400.00          | \$428,400.00          | \$0.00              |
| <b>Total</b>                 | <b>\$4,443,418.00</b> | <b>\$4,342,276.50</b> | <b>\$101,141.50</b> |
| <b>47 ft Project Depth</b>   |                       |                       |                     |
|                              | Cost                  | Federal Cost          | Non-Federal Cost    |
| Oxygen Injection System      | \$1,210,400.00        | \$1,059,450.00        | \$150,950.00        |
| Inner Harbor O&M Dredging    | \$2,672,080.00        | \$2,672,080.00        | \$0.00              |
| Channel Extension            | \$49,199.00           | \$48,677.00           | \$522.00            |
| Mitigation Features Dredging | \$114,000.00          | \$114,000.00          | \$0.00              |
| CSS Georgia Curation         | \$20,000.00           | \$20,000.00           | \$0.00              |
| Fish Passage O&M             | \$50,000.00           | \$50,000.00           | \$0.00              |
| Long Term Monitoring         | \$428,400.00          | \$428,400.00          | \$0.00              |
| <b>Total</b>                 | <b>\$4,544,079.00</b> | <b>\$4,392,607.00</b> | <b>\$151,472.00</b> |
| <b>48 ft Project Depth</b>   |                       |                       |                     |
|                              | Cost                  | Federal Cost          | Non-Federal Cost    |
| Oxygen Injection System      | \$1,311,000.00        | \$1,109,750.00        | \$201,250.00        |
| Inner Harbor O&M Dredging    | \$2,672,080.00        | \$2,672,080.00        | \$0.00              |
| Channel Extension            | \$50,373.00           | \$49,264.00           | \$1,109.00          |
| Mitigation Features Dredging | \$114,000.00          | \$114,000.00          | \$0.00              |
| CSS Georgia Curation         | \$20,000.00           | \$20,000.00           | \$0.00              |
| Fish Passage O&M             | \$50,000.00           | \$50,000.00           | \$0.00              |
| Long Term Monitoring         | \$428,400.00          | \$428,400.00          | \$0.00              |
| <b>Total</b>                 | <b>\$4,645,853.00</b> | <b>\$4,443,494.00</b> | <b>\$202,359.00</b> |

Table 12.4-4: Annual O&amp;M Cost Increase &amp; Total O&amp;M Annual Costs due to SHEP (47-Ft Project)

|                                   | ANNUAL O&M INCREASE COST DUE TO EXPANSION |              |              |              |              |              |              |              |              |              | ANNUAL O&M PROJECT COST AFTER EXPANSION |      |      |      |      |      |      |      |      |      |
|-----------------------------------|-------------------------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|-----------------------------------------|------|------|------|------|------|------|------|------|------|
|                                   | 2010                                      | 2011         | 2012         | 2013         | 2014         | 2015         | 2016         | 2017         | 2018         | 2019         | 2010                                    | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| Inner Harbor O&M Dredging         | \$2,672,080                               | \$2,709,489  | \$2,752,841  | \$2,799,639  | \$2,847,233  | \$2,895,636  | \$2,944,862  | \$2,994,925  | \$3,045,838  | \$3,097,618  |                                         |      |      |      |      |      |      |      |      |      |
| Bar Channel O&M Dredging          | \$49,199                                  | \$49,888     | \$50,686     | \$51,548     | \$52,424     | \$53,315     | \$54,222     | \$55,143     | \$56,081     | \$57,034     |                                         |      |      |      |      |      |      |      |      |      |
| Oxygen Injection System           | \$1,210,400                               | \$1,227,346  | \$1,246,983  | \$1,268,182  | \$1,289,741  | \$1,311,667  | \$1,333,965  | \$1,356,642  | \$1,379,705  | \$1,403,160  |                                         |      |      |      |      |      |      |      |      |      |
| Mitigation Features O&M Dredging  | \$114,000                                 | \$115,596    | \$117,446    | \$119,442    | \$121,473    | \$123,538    | \$125,638    | \$127,774    | \$129,946    | \$132,155    |                                         |      |      |      |      |      |      |      |      |      |
| Fish Passage O&M                  | \$50,000                                  | \$50,700     | \$51,511     | \$52,387     | \$53,277     | \$54,183     | \$55,104     | \$56,041     | \$56,994     | \$57,963     |                                         |      |      |      |      |      |      |      |      |      |
| CSS Georgia Curdion               | \$20,000                                  | \$20,280     | \$20,604     | \$20,955     | \$21,311     | \$21,673     | \$22,042     | \$22,416     | \$22,798     | \$23,185     |                                         |      |      |      |      |      |      |      |      |      |
| Long Term Monitoring              | \$428,400                                 | \$434,398    | \$441,348    | \$448,851    | \$456,481    | \$464,242    | \$472,134    | \$480,160    | \$488,323    | \$496,624    |                                         |      |      |      |      |      |      |      |      |      |
|                                   | \$4,544,079                               | \$4,607,696  | \$4,681,419  | \$4,761,003  | \$4,841,940  | \$4,924,253  | \$5,007,966  | \$5,093,101  | \$5,179,684  | \$5,267,738  |                                         |      |      |      |      |      |      |      |      |      |
|                                   | ANNUAL O&M INCREASE COST DUE TO EXPANSION |              |              |              |              |              |              |              |              |              | ANNUAL O&M PROJECT COST AFTER EXPANSION |      |      |      |      |      |      |      |      |      |
|                                   | 2010                                      | 2011         | 2012         | 2013         | 2014         | 2015         | 2016         | 2017         | 2018         | 2019         | 2010                                    | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| Inner Harbor O&M Dredging         | \$21,487,100                              | \$21,787,919 | \$22,136,526 | \$22,512,847 | \$22,895,365 | \$23,284,790 | \$23,680,631 | \$24,083,202 | \$24,492,617 | \$24,908,991 |                                         |      |      |      |      |      |      |      |      |      |
| Bar Channel O&M Dredging          | \$3,416,423                               | \$3,464,253  | \$3,519,681  | \$3,579,516  | \$3,640,367  | \$3,702,254  | \$3,765,192  | \$3,829,200  | \$3,894,297  | \$3,960,500  |                                         |      |      |      |      |      |      |      |      |      |
| Oxygen Injection System           | \$1,210,400                               | \$1,227,346  | \$1,246,983  | \$1,268,182  | \$1,289,741  | \$1,311,667  | \$1,333,965  | \$1,356,642  | \$1,379,705  | \$1,403,160  |                                         |      |      |      |      |      |      |      |      |      |
| Mitigation Features O&M Dredging  | \$114,000                                 | \$115,596    | \$117,446    | \$119,442    | \$121,473    | \$123,538    | \$125,638    | \$127,774    | \$129,946    | \$132,155    |                                         |      |      |      |      |      |      |      |      |      |
| Fish Passage O&M                  | \$50,000                                  | \$50,700     | \$51,511     | \$52,387     | \$53,277     | \$54,183     | \$55,104     | \$56,041     | \$56,994     | \$57,963     |                                         |      |      |      |      |      |      |      |      |      |
| CSS Georgia Curdion               | \$20,000                                  | \$20,280     | \$20,604     | \$20,955     | \$21,311     | \$21,673     | \$22,042     | \$22,416     | \$22,798     | \$23,185     |                                         |      |      |      |      |      |      |      |      |      |
| Long Term Monitoring              | \$428,400                                 | \$434,398    | \$441,348    | \$448,851    | \$456,481    | \$464,242    | \$472,134    | \$480,160    | \$488,323    | \$496,624    |                                         |      |      |      |      |      |      |      |      |      |
| Estimated \$ to Fully Maintain    | \$26,726,323                              | \$27,100,492 | \$27,534,099 | \$28,002,179 | \$28,478,216 | \$28,962,346 | \$29,454,706 | \$29,955,436 | \$30,464,678 | \$30,982,578 |                                         |      |      |      |      |      |      |      |      |      |
| Current Funding Appropriation     | \$13,000,000                              | \$13,000,000 | \$13,000,000 | \$13,000,000 | \$13,000,000 | \$13,000,000 | \$13,000,000 | \$13,000,000 | \$13,000,000 | \$13,000,000 |                                         |      |      |      |      |      |      |      |      |      |
| Additional Need to Fully Maintain | \$13,726,323                              | \$14,100,492 | \$14,534,099 | \$15,002,179 | \$15,478,216 | \$15,962,346 | \$16,454,706 | \$16,955,436 | \$17,464,678 | \$17,982,578 |                                         |      |      |      |      |      |      |      |      |      |

\* All costs are totals assuming a 47' project. No breakout of Federal vs. Sponsor cost have been applied. (100% Fed to 45', 50/50 Fed/Non-Fed from 45' to NEI).

## 13.0 COST ENGINEERING

### 13.1 CONSTRUCTION COST NARRATIVE - CURRENT WORKING ESTIMATE

The Cost Engineering narrative was prepared to describe the Current Working Estimate (CWE) of alternative plan evaluations for the Savannah Harbor Expansion Project (SHEP) deepening. This narrative also provides details for the selected plan of a 47-ft design depth. The alternatives evaluated were to deepen the harbor design depth, existing 42 ft, to a design depth between 44 ft and 48 ft below MLLW. The costs are summarized and listed below in the Code of Accounts format and are based upon October 2010 price levels.

A CWE for construction (dredging & mitigation) and non-construction features were developed for each design depth alternative of 44 ft to 48 ft. The existing (design) depth for the Savannah Harbor is 42 ft below MLLW. Existing advance maintenance depths range from 2 ft to 8 ft below the design depth at various locations. Each alternative includes 2-ft of allowable overdepth dredging quantities. A summary of costs for all alternative design depths (44 ft to 48 ft) is shown in **Table 13.1.1** below and Table 10-5 of the General Reevaluation Report (GRR).

Evaluations of impacts and benefits compared to costs determined the National Economic Development (NED) plan to be a 47-ft design depth (plus 2-ft of allowable overdepth).

The CWE for the selected plan of 47-ft design depth includes new deepening quantities to be dredged, 2-feet allowable overdepth quantities, dredging of river wideners for ship meeting areas, required mitigation features including onsite dissolved oxygen injection systems, river salinity mitigation features, raising existing disposal area dikes, marsh restoration, cadmium sediment removal, adaptive management, environmental monitoring, removal of the Confederate vessel CSS Georgia, Real Estate, Planning, Engineering and Design, Construction Management, and the addition of Navigation Aids.

The CWE and Code of Account features for 47-ft design depth are further broken down into more detail in the Microcomputer Aided Cost Estimating System (MCACES) MII estimate discussed below and shown in Attachment 2 of this appendix (Appendix C: Engineering Investigations).

A Total Project Cost Summary (TPCS), Attachment 2 of this appendix (Appendix C: Engineering Investigations), identifies the CWE for the 47-ft design depth for October 2010 as \$483,738,000 (\$604,673,000 with 25% contingency) and fully funded to midpoint of construction as \$688,118,000 with contingency.

The TPCS estimate was reviewed by Cost Center DX for certification during the ATR. The TPCS and COST CENTER DX certification is included with Attachment 2 of this appendix (Appendix C: Engineering Investigations).

Overall construction midpoint for dredging and mitigation will vary depending on contract acquisition method but overall is estimated to be October 2014. Construction completion is estimated to be OCTOBER 2016 with post construction monitoring and adaptive management to follow construction completion.



Cost Estimates were prepared under guidance given in the Corps of Engineers Regulation ER 1110-2-1302, *Civil Works Cost Engineering* and ETL 1110-2-573, *Construction Cost Estimating Guide for Civil Works*, dated 30 Sep 2008. The Corps of Engineers Dredge Estimating Program (CEDEP) was used in developing dredging costs throughout the project for medium hopper dredges and large pipeline cutterhead dredges. A Cost Risk and Schedule Analysis (CRSA) was conducted with the Project Delivery Team and the Center of Expertise at Walla Walla District to support a 25% contingency percentage for risk and uncertainty. A final copy of the Cost Risk Report, Risk Register, Cost models, and sensitivity analysis is included as Attachment 4 of this appendix (Appendix C: Engineering Investigations).

Table 13.1-1: Cost Summary for All Alternative Project Depths (44 ft to 48 ft)

| WBS NO.                                                             | FEATURE DESCRIPTION                                 | 44 FT                | 45 FT                | 46 FT                | 47 FT                | 48 FT                |
|---------------------------------------------------------------------|-----------------------------------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| 1                                                                   | REAL ESTATE                                         | \$4,701,250          | \$15,553,250         | \$17,666,250         | \$18,605,625         | \$21,825,625         |
| 6                                                                   | FISH & WILDLIFE FACILITIES - Mitigation             | \$198,592,370        | \$202,598,595        | \$206,231,095        | \$212,292,345        | \$215,777,345        |
|                                                                     | Fish Passage - New Savannah Bluff Lock & Dam        | \$29,577,470         | \$29,577,470         | \$29,577,470         | \$29,577,470         | \$29,577,470         |
|                                                                     | McCoy Cut Diversion Channel                         | \$2,905,103          | \$2,905,103          | \$2,905,103          | \$2,905,103          | \$2,905,103          |
|                                                                     | Deepen McCoy Cut, Upper Middle & Little Back Rivers | \$0                  | \$9,109,975          | \$9,109,975          | \$9,109,975          | \$9,109,975          |
|                                                                     | Rock Berm At Mouth of Back River                    | \$21,030,061         | \$21,030,061         | \$21,030,061         | \$21,030,061         | \$21,030,061         |
|                                                                     | Close Rifle Cut                                     | \$828,914            | \$828,914            | \$828,914            | \$828,914            | \$828,914            |
|                                                                     | Remove Tidegate Piers And Abutments                 | \$3,575,643          | \$3,575,643          | \$3,575,643          | \$3,575,643          | \$3,575,643          |
|                                                                     | Embankment At Tidegate Removal                      | \$17,969,583         | \$17,969,583         | \$17,969,583         | \$17,969,583         | \$17,969,583         |
|                                                                     | Close Lower McCoy's Cut Western Arm                 | \$1,421,946          | \$1,421,946          | \$1,421,946          | \$1,421,946          | \$1,421,946          |
|                                                                     | Boat Ramp                                           | \$624,953            | \$624,953            | \$624,953            | \$624,953            | \$624,953            |
|                                                                     | Construct Marsh At Disposal Island 1S               | \$17,594,949         | \$17,594,949         | \$17,594,949         | \$17,594,949         | \$17,594,949         |
|                                                                     | Water Impoundment                                   | \$25,187,500         | \$25,187,500         | \$25,187,500         | \$25,187,500         | \$25,187,500         |
|                                                                     | Brond Berm Sediment Basin - Back River              | \$8,362,500          | \$8,362,500          | \$8,362,500          | \$8,362,500          | \$8,362,500          |
|                                                                     | Mitigation Costs For Striped Bass                   | \$2,085,000          | \$356,250            | \$613,750            | \$3,300,000          | \$3,410,000          |
|                                                                     | Construct Dissolved Oxygen Injection Sys            | \$67,428,750         | \$64,033,750         | \$67,428,750         | \$70,803,750         | \$74,178,750         |
| 12                                                                  | NAVIGATION, PORTS AND HARBORS                       | \$160,137,581        | \$193,721,068        | \$222,579,256        | \$251,169,942        | \$279,735,740        |
|                                                                     | Mobilization And Demeolization                      | \$26,500,000         | \$27,635,000         | \$27,635,000         | \$29,625,000         | \$30,500,000         |
|                                                                     | Dredging                                            | \$118,464,265        | \$149,259,623        | \$175,073,167        | \$199,292,615        | \$224,612,951        |
|                                                                     | Disposal Area Requirements - Dike Raises            | \$1,188,316          | \$2,851,445          | \$5,896,089          | \$8,267,328          | \$10,637,789         |
|                                                                     | Cadmium Sediment - Dike Raises 14A & 14B            | \$11,875,000         | \$11,875,000         | \$11,875,000         | \$11,875,000         | \$11,875,000         |
|                                                                     | Debris Removal                                      | \$2,110,000          | \$2,110,000          | \$2,110,000          | \$2,110,000          | \$2,110,000          |
| 31                                                                  | MITIGATION MONITORING and ADAPTIVE MGT              | \$58,792,500         | \$59,818,750         | \$60,160,000         | \$60,195,000         | \$60,468,750         |
| 18                                                                  | CULTURAL RESOURCES - CSS Georgia                    | \$13,914,375         | \$13,914,375         | \$13,914,375         | \$13,914,375         | \$13,914,375         |
| 30                                                                  | PLANNING, ENGINEERING & DESIGN                      | \$21,933,037         | \$23,873,642         | \$25,522,693         | \$27,257,824         | \$28,887,677         |
| 31                                                                  | CONSTRUCTION MANAGEMENT                             | \$10,966,519         | \$11,936,821         | \$12,761,346         | \$13,628,912         | \$14,443,838         |
| <b>PROJECT FIRST COSTS WITH CONTINGENCIES</b>                       |                                                     | <b>\$469,037,632</b> | <b>\$521,416,501</b> | <b>\$558,835,015</b> | <b>\$597,064,023</b> | <b>\$635,053,350</b> |
|                                                                     | Berthing Areas                                      | \$2,216,414          | \$2,401,299          | \$2,551,629          | \$2,583,564          | \$2,854,826          |
|                                                                     | Navigation Aids                                     | \$5,025,000          | \$5,025,000          | \$5,025,000          | \$5,025,000          | \$5,025,000          |
| <b>PROJECT FIRST COST WITH ASSOCIATED COSTS &amp; CONTINGENCIES</b> |                                                     | <b>\$476,279,046</b> | <b>\$528,842,799</b> | <b>\$566,411,644</b> | <b>\$604,672,587</b> | <b>\$642,933,176</b> |
| <b>TOTAL - ROUNDED OCT 2010 PRICE LEVEL</b>                         |                                                     | <b>\$476,279,000</b> | <b>\$528,843,000</b> | <b>\$566,412,000</b> | <b>\$604,673,000</b> | <b>\$642,933,000</b> |

Current MCACES Estimate Prepared: January 4, 2012.

Engineering Investigations  
Savannah Harbor Expansion Project

### 13.2 CODE OF ACCOUNTS

A CODE OF ACCOUNTS format is established to provide a consistent organization of major costs by task and type. Summary of the Code of Accounts for the 47 ft project depth is shown in **Table 13.2-1**.

**Table 13.2-1: Summary of Code of Accounts for the 47 ft Project Depth**

| Code Of Accounts                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 47 ft Depth<br>\$ millions |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| <u>Lands and Damages (01)</u> – Real Estate                                                                                                                                                                                                                                                                                                                                                                                                                                                       | \$ 15                      |
| <u>Fish and Wildlife Facilities (06)</u><br>Fish Passage – New Savannah Bluff Lock & Dam<br>Mitigation Plan 6a –<br>McCoy's Cut Diversion Structure<br>Close Western McCoy Cut Connection<br>Deepening McCoy's Cut – Little Back and Middle Back River<br>Close Rifle Cut Channel<br>Tidegate Removal<br>Broad Berm Stone Weir<br>Broad Berm Fill<br>Tidegate Embankment Removal<br>Marsh Restoration at Island 1S<br>New Boat Ramp<br>Raw Water Impoundment<br>Dissolved Oxygen Generation Sites | \$170                      |
| <u>Navigation, Ports, and Harbors (12)</u><br>Outer Bar Channel Dredging<br>Inner Bar Channel Dredging<br>Misc - Raise Existing Disposal Dikes<br>Navigation Aids                                                                                                                                                                                                                                                                                                                                 | \$207                      |
| <u>Cultural Resource Preservation (18)</u> – Recovery of CSS Georgia                                                                                                                                                                                                                                                                                                                                                                                                                              | \$ 11                      |
| <u>Planning, Engineering and Design (30)</u> – Investigations, Plans and Specifications                                                                                                                                                                                                                                                                                                                                                                                                           | \$ 22                      |
| <u>Construction Management (31)</u> – Contract Admin, Construction Inspection & Adaptive Management                                                                                                                                                                                                                                                                                                                                                                                               | \$ 59                      |
| <b>TOTAL</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | <b>\$484</b>               |
| Project Cost and Schedule Risk Analysis: Contingency Summary 25%                                                                                                                                                                                                                                                                                                                                                                                                                                  | \$121                      |
| <b>TOTAL with Contingency</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | <b>\$605</b>               |

Lands and Damages (01) – The estimated cost was furnished by the Real Estate Division, Savannah District, and is discussed in the Real Estate Appendix.

Fish and Wildlife Facilities (06) – This account includes costs for mitigation including a fish passage structure at New Savannah Bluff Lock and Dam, salinity mitigation for deepening the harbor as outlined by Mitigation Plan 6a, creation of a marsh island habitat at Disposal Area 1S, removal of the Tidegate structure, a 97 MG raw water storage impoundment (a 25 acre footprint with 20 ft high earthen berm) with mechanical mixing, and an on-site oxygen generated D.O. injection systems at two (2) locations along the harbor.

Emphasis was placed on accuracy of quantities, material characteristics, and detail costs during evaluation of alternative plans to develop the CWE Plan. The reasonableness of costs developed was evaluated based on historical data, discussions with industry, crew production rates and construction methods based on similar projects.

A Fish Passage at New Savannah Bluff Lock and Dam (FPSBLD) will be constructed to allow fish passage upstream of the dam. The structure would consist of a rock ramp constructed around the side of the dam. The primary construction tasks involve excavation of approximately 275,000 cubic yards of material around the end of the dam and placement of 116,000 tons of rip rap and boulder weir stone. A submerged sheet pile wall would be constructed at a height of 3 to 4 feet above the river bottom to guide fish in both upstream and downstream directions. Existing gates 1 and 5 would also be raised from 12 ft to 15 ft.

A combination of features will be constructed to mitigate for potential salinity impacts in the river as described by Mitigation Plan 6a. More detail of all these features are described in Chapter 8.1 of the Engineering Appendix. McCoy's Cut Diversion feature is diverting a portion of flow from Front River into the upstream areas at McCoy's Cut. This feature includes constructing a diversion structure with 168 tons of sheet pile wall and 7,100 tons of GADOT Armor Stone at the entrance to McCoy's Cut. Additionally a portion of lower western McCoy's connection will be closed using over 5,100 tons of GADOT TYPE 1 stone.

McCoy's Cut and upper portions of Middle River and Little Back River will be deepened to accommodate the additional diverted flow. Estimated deepening quantities excavated for McCoy's Cut, Middle and Little Back Rivers will be 315,000 cy. This material will be disposed of in the existing Dredge Confined Disposal Facilities used for dredged material disposal.

Rifle Cut waterway will be closed using 3,300 cy of fill sediment and 2,500 tons of GADOT, Type 1 rip rap to improve flow diversion.

Additional features include removal/demolition of the Tidegate structure piers and abutment (elevated walkways and associated appurtenances) as well as the Tidegate embankment removal to widen the river. The approximately 1,000,000 cubic yards of embankment at the Tidegate abutments will be removed and disposed of in either the Broad Berm fill area, if it is suitable fill, or existing confined dredge disposal areas.

A submerged Broad Berm stone weir will be constructed at the conversion of Back River with Front River. The stone weir is located downstream of the Tidegates and sedimentation basin. The stone weir will be constructed of 97,000 tons of GADOT, TYPE 1 stone to -9.5 MLLW.

In addition, a Broad Berm fill, upstream or behind the stone weir, will require 1.2 million cubic yards of suitable (sandy) fill material. The suitable fill is assumed to come from existing dredge confined disposal areas and/or the embankment removal at the Tidegate.

A marsh island habitat restoration of 42 acres will be developed and restored at the current location of Disposal Area 1S to an elevation of +7.6 ft MLLW. Construction includes excavation/grading of 435,000 cy of material with assumed disposal into existing confined disposal areas.

A proposed public access Boat Ramp on Hutchinson Island includes a 2 lane concrete boat ramp with floating dock, 20 space trailer parking, handicap accessible and single car parking spaces.

Onsite dissolved oxygen injection systems will be developed and constructed at two locations along the river. The two sites will have multiple Speece cones to generate oxygen into the harbor.

A 97 million gallon (77.5 MG usable) Raw Water Storage Impoundment will be constructed in order to stabilize and reduce any necessary chloride concentrations before being pumped into the City of Savannah's water treatment plant. An earthen embankment with HDPE liner, mechanical mixing system, four (4) pump stations rated at 21 MGD each, and a powdered activated carbon treatment system will be included in the construction.

Navigation, Ports, and Harbors (12) – The 47-ft NED plan includes dredging of approximately 23,603,000 cy of material from 38 miles of both the Ocean Bar entrance channel and Inner River Harbor.

River Stations are labeled 4+000 to 103+000 for an Inner Harbor design depth of 47-ft MLLW plus 2-ft of allowable overdepth. The Outer Bar includes 2 ft additionally below MLLW, or 49-ft plus 2-ft of allowable overdepth in outer ocean bar 4+000 to -97+680.

Also included in Account 12 are costs for raising existing disposal area dike elevations/capacity, debris removal, new navigation aids, and removal/containment of any cadmium sediment dredged from the river. Pricing was developed assuming both medium hopper dredges and large pipeline cutterhead dredges may be used.

Average bank heights for new work dredging are approximately 5-6 ft. Quantities also include 2 ft of allowable pay overdepth (to ensure a sufficient design depth of 47-ft is met for vessel traffic). Areas and depths of advanced maintenance will be maintained or remain at the same reaches/locations as they have been located historically.

The Corps of Engineers Dredge Estimating Program (CEDEP) was used to determine dredging average unit costs for each reach of location along the 38 miles. Significant factors input into CEDEP for determining unit prices and dredging time includes: Dredge Area, Dredge Depth-bank height, Non-pay overdepth cubic yardage, Material Factors – silt, sand, and clay, Pumping Distance or Haul Distance to Disposal Areas, EWT- Effective Work Time when dredging, Production cy/hr when dredging, Production cy/day average, and other monthly costs – such as land equipment, field office overhead, turtle monitoring, site specific maintenance costs, pipeline wear costs and fuel pricing. All of these factors are critical for developing a reasonable price estimate for various locations and conditions. The equipment most likely to be used for dredging excavation was assumed to be:

- A hydraulic pipeline dredge for the Inner Harbor (Stations 4+000 to 103+000), about 19 miles. Dredge material will be placed into existing confined disposal areas 13A, 14A, 14B and Jones Oyster Island.
- A combination of hydraulic pipeline (loading scows & tug hauled) and hopper dredges for the Outer Ocean Bar (Stations 4+000 to -98+600), about 19 miles. Material will be placed in the existing EPA approved ODMS.

The cost estimate for all dredging construction anticipates two contracts and covers a four-year period of concurrent work. The Inner Harbor will be one contract and the Ocean Bar will be another contract.

Cultural Resource Preservation (18) – This account includes the costs for removal of remnants of the CSS Georgia and was provided by Savannah District archeologist. The costs are based on discussions with the various archeological firms who are experienced in removal and conservation of historical shipwrecks in tidal waters. The CSS Georgia has been impacted severely over the years due to O&M dredging operations.

Planning, Engineering and Design (30) – 5% of construction costs were included in this account and supported by those responsible for performing each activity during PED. This account includes plans and specifications, field investigations and surveys, cost estimates, engineering during construction, and project management.

Construction Management (31) – 2.5% of construction costs were included for supervision and administration of the contracts by construction management, hydrologic surveys during construction, contracting personnel during construction, environmental/physical monitoring, and adaptive management following monitoring phases.

Project Cost and Schedule Risk Analysis: Contingency – An overall project contingency of 25% was developed during a cost/risk analysis conducted with the Project Delivery Team (PDT) and Walla Walla District Cost Center of Expertise.

The updated and final CRSA which includes a Cost Risk Report, Risk Register, Cost models and sensitivity analysis is included as Attachment 4 of this appendix (Appendix C: Engineering Investigations).

### 13.3 ASSUMPTIONS AND SCHEDULE

Overall construction period for dredging and mitigation features is anticipated to be approximately 4 +/- years, FEBRUARY 2013 to OCTOBER 2016. Construction contracts for dredging and mitigation are assumed to be concurrent during this 4 year period. Pre construction environmental monitoring and monitoring during construction will be performed. Post construction monitoring and adaptive management for mitigation will follow dredging and mitigation construction.

- GENERAL CONSTRUCTION
- DREDGING – INNER HARBOR AND OUTER BAR CHANNEL
- MITIGATION FEATURES
  - Fish Passage Structure
  - Rip Rap at McCoy's Cut Diversion, Rifle Cut Closure, and Broad Berm Stone Weir
  - Deepening McCoy's Cut, Little and Middle Back Rivers
  - Fill for Rifle Cut
  - Removal of Tidegate – Abutments and Piers
  - Tidegate Embankments Removal
  - Broad Berm fill
  - Marsh Restoration at Island 1S
  - Boat Ramp
  - Dissolved Oxygen injection systems
  - Raw Water Storage Impoundment
- PROJECT COST AND SCHEDULE RISK ANALYSIS

#### 13.3.1 General Construction

The initial construction will be to raise dikes to have adequate capacity for dredge disposal quantities. Construction of Dissolved Oxygen systems, raw water storage impoundment, and removal of the CSS GEORGIA will be concurrent with raising of the dikes.

#### 13.3.2 Dredging - Outer Bar and Inner Harbor

The Ocean Bar Channel contract was assumed to begin November 2013 and disposal will be in the ODMDS. The OUTER BAR was assumed to be constructed with both hopper dredges and/or hydraulic cutterhead pipeline dredges. Either pipeline (filling dump scows and tug hauled) and/or the hopper dredges would place material in the ODMDS.

For the Outer Ocean Bar, cutterhead pipeline dredges (filling dump scows and tug hauled to the ODMDS for disposal) would not be restricted to work only during the winter dredging season. Hopper dredges would be allowed to work during the months of December 1 thru March 31.

The Inner Harbor contractor was assumed to place dredged material into existing confined disposal areas 13, 14A, 14B and Jones Oyster Island. The Inner Harbor contractor would be required to avoid upstream of Station 66+310 during the period April 1 – May 15 to avoid impacts to striped bass fishery

resources. Dredging the Inner Harbor between June 1 and September 30 may also be impacted if dissolved oxygen levels fall below 4 to 5 ppm.

Several areas to be dredged within the Inner Harbor contain cadmium sediments. These areas are to be placed in disposal dikes 14A & 14B. These dikes will then be capped with non-cadmium dredged materials. Construction sequence will be important to dredge cadmium materials first and then cap with non-cadmium dredged material.

There will be limited debris removal in both contracts made necessary because of sinkers and other miscellaneous debris which may have accumulated since the last deepening.

Disposal of 12 to 15 million cys of material from the Inner Harbor, Stations 4+000 to 103+000 would be into existing Confined Disposal Facilities labeled 13A, 14A&B, and Jones Oysterbed Island.

Disposal of 11 to 13 million cys of material from the Outer Harbor Bar Stations 4+000 to -97+680 would be into the existing EPA approved ODMDS.

The average dredging production (18,000 to 21,000 cy/day) and unit costs appear reasonable when compared to historical information for production and pricing (adjusted to October 2010).

### 13.3.3 Mitigation Features

The Fish Passage at the New Savannah Bluff lock and dam will be constructed by excavating around the end of the dam and placement of rock ramp rip rap and weir stone. The contract time period was assumed to be 700 cal days. There will be no downstream inwater construction during the months of February through May.

RIP RAP features for the Diversion Structure at McCoy's Cut; Closure of lower Arm at McCoy's cut; Rifle cut closure; and the stone weir at Sediment Basin Broad berm were assumed to be constructed by loading rip rap onto material barges from docks and hauled by tug to the individual sites. RIP RAP will be dumped and/or placed using barge mounted cranes with rock boxes or buckets. The contract time period assumed for these contracts are listed below.

- Diversion Structure at McCoy's Cut (includes 140 LF sheetpile) – 150 cal days
- Western Lower Arm at McCoy's Cut – 150 cal days
- Rifle Cut closure (Rip rap + Fill) – 150 cal days
- Broad Berm weir stone – 420 cal days

Deepening excavation for McCoy's Cut, Middle and Little Back River channels was assumed to be by barge mounted clamshell/shovels loading material into hopper barges. Hopper barges will then be tugged to the existing confined disposal sites and unloaded or pumped out into the disposal areas. The contract time period assumed for this contract is 510 cal days.

Suitable Fill material for Rifle Cut closure was assumed to come from within existing confined dredge disposal areas. The material to be suitable must be mostly sandy. Material would be excavated from the existing disposal areas and loaded into hopper barges for transport. Hopper barges would be transported by tug and then unloaded/pumped out at the construction fill site.



Rifle Cut closure (Rip rap + Fill) – see above anticipated contract period.

Removal of Tidegate Abutments and Piers – It was assumed the 15 concrete piers, walkways, and abutments will be broken down by blasting/mechanical methods. Concrete pieces would be loaded by barge mounted cranes onto material barges and/or land for stockpiling and removal from the site. Removal of earthen abutments/embankments, existing rip rap, stacked gates, conduit hardware, lighting, handrails and utilities are also required. The contract time period was assumed to be 365 cal days.

Tidegate embankments (approx 1,000,000 cy's) are to be excavated to widen the river. Suitable embankment (sandy) material may be excavated by barge mounted equipment and placed into the nearby Broad Berm fill. One half of material (525,000 cy) was assumed to be placed onto flat or confined hopper barges and then unloaded by dumping or pumpout into the Broad Berm. Turbidity limits cannot be exceeded when performing this work. The remaining unsuitable material from embankments was assumed to be pumped or dredged into the existing confined disposal facilities. The contract time period was assumed to be 540 cal days.

Broad Berm fill material, 1,200,000 cubic yards, was assumed to come from either/or Tidegate embankment removal or existing confined dredge disposal areas. It was assumed suitable material in the disposal areas would be excavated from the existing disposal areas and loaded into hopper barges for transport. Hopper barges would be transported by tug and then unloaded/pumped out at the construction fill site areas. Small portable pipeline cutterhead dredges may also be used in the disposal areas or at the Tidegate location to pump suitable material into the fill area.

Marsh Restoration at Area 1S (Onslow Island) – Areas designated to be restored must be cleared and grubbed. It was assumed that an entrance channel will be excavated from Middle River into the island area using barge mounted crane clamshell/shovels and material loaded into hopper barges. Hopper barges will be towed to the existing confined disposal areas 12 thru 14 and unloaded/pumped out. The entrance channel excavation will continue into the interior of the island and remove approximately 425,000 cy of material with disposal into the CDA's 12 thru 14. Land equipment will then backfill the excavated area and grade to elevation +7.6 MLLW. Suitable material may be used to fill Broad Berm near existing sedimentation basin. The contract time period was assumed to be 540 cal days.

A new public access boat ramp will be constructed on the North side of Hutchinson Island (at the site where Tidegate embankment abutment is removed). The public access Boat Ramp includes a 2 lane concrete boat ramp with floating dock, 20 space trailer parking, handicap accessible and single car parking spaces. The contract time period was assumed to be 365 cal days.

The Dissolved Oxygen injection systems will be land based at two locations, with water being withdrawn from the river, super-saturated with oxygen, and returned to the river. The sites will require development of access roads, concrete platform for work areas and to support Speece cones, intake/discharge piping systems, electrical service, perimeter fencing and multiple Speece cones per site. The contract time period was assumed to be 365 cal days for each location.

A Raw Water Storage Impoundment will be constructed of earthen embankment with HDPE liner, mechanical mixing system, four(4) pump stations rated at 21 MGD each, and a powdered activated carbon treatment system will be included in the construction. The contract time period was assumed to be 365 cal days.

### 13.3.4 Project Cost and Schedule Risk Analysis: Contingency

An overall project contingency of 25% was originally developed during a cost/risk analysis conducted with the PDT and Walla Walla District Cost Center of Expertise. The 25% contingency represents an 80% confidence level for the project overall. Details of the cost/risk analysis are further described in the Project Cost and Schedule Risk Analysis Report (CSRA) which is included as Attachment 4 of this appendix (Appendix C: Engineering Investigations).

A contingency percentage is the amount added to an estimate to allow for uncertainty of items, conditions, or events that impact a project. Many of these items are known to exist but it is uncertain how much these items will vary depending on many factors.

The overall contingency of 25% was the result of statistical Monte Carlo simulations for many elements within each cost and schedule that could occur during the life of the project. The best examples of risks/uncertainties are fluctuations of fuel prices, labor, material prices or availability, how work will be performed, competitive bid environment, multiple year contracts and schedules, funding constraints, site condition material factors and quantities, etc.

Experience shows that many items formulated during the estimate construction first costs will vary (be uncertain) during the life of a project and likely result (overall) in additional costs. In other words, many items are known factors with variances which will increase/decrease costs in some manner. The question is how to account for the likelihood of these items changing the project costs and what confidence level cost changes will be correct (or costs exceeded).

Questions of risk and uncertainty may be addressed by a problematic risk analysis. A risk analysis is a systematic and comprehensive method to evaluate uncertainty and risks. Risks were characterized by the magnitude of possible uncertainties and the probability of occurrence for each item or event. Details for events identifying likelihood, impact, and risk level are shown in the Risk Register, Attachment 4 of this appendix (Appendix C: Engineering Investigations).

Using computer software to conduct Monte Carlo simulations and statistical sensitivity, key risk drivers were identified as listed below:

- Risk Events I-37 & I-38 fuel increases from \$2.70/gallon up to \$6.00/gallon
- Risk Event I-20 & I-36 competition or competitive bid environment
- Risk Event I-41 Construct the Dissolved Oxygen Injection System
- Risk Event I-33 construction contract schedules for dredging

Together these risk driver's are the majority of the statistical cost variance.

Cost contingencies calculated for the 80% confidence level resulted in a 25% contingency. The 80% confidence level means there is an 80% certainty that project costs will not exceed the total with contingency.

## 14.0 VALUE ENGINEERING

A Value Engineering (VE) Study for the project was conducted in Savannah, Georgia on May 20-22, 2008. The VE team was comprised of members from Wilmington, Charleston, and Savannah Districts USACE, Georgia DOT, and Concord Project Consulting, Inc. and associated consultants. Findings and recommendations from the VE team are presented in full in their report titled *Value Engineering Study Summary Report* which is included in the Engineering Investigations Supplemental Materials.

Value Engineering is a process used to study the functions a project is to achieve. The VE Team took a critical look at how these functions are proposed to be met and it identified alternative ways to achieve the equivalent function while increasing the value and the benefit ratio of the project. In the end, it is hoped that the project will realize a reduction in cost, but increased value is the focus of the process, rather than simply reducing cost. USACE guidance on conducting VE studies in place at the time the SHEP VE study was conducted was ER 11-1-321, dated 28 February 2005. Current USACE guidance on conducting VE studies is ER 11-1-321 Change 1, dated 1 January 2011.

The VE Study identified \$34,221,436 in potential savings for project construction. Each of the proposals included in the VE Study recommendations was evaluated by the Engineering team to determine constructability and performance to meet project requirements. A summary of the team's findings is included in **Table 14.0-1**. Overall, all of the major design changes proposed (for savings more than \$1 million) were not considered to be viable alternative designs.

The major savings identified were for proposals 4 and 7 were both for alternative methods for constructing the McCoys Cut diversion structure. After further analysis, it was determined that an error had been made in the original rock volume for this structure. When the revised volume was carried through to the cost estimate for this structure, the actual cost for construction of a rock structure was \$400,000, which was much less than the cost previously estimated for this feature or the costs estimated for proposals 4 and 7. Modification of this structure was not determined to be cost effective. Some of the smaller project recommendations, such as reuse of concrete from the tidegate or use of sand from 2A for the sand sill at Rifle Cut (proposals 3 and 6) may be cost effective and will be considered during the planning, engineering and design phase of this contract, when more site specific information is available.

Subsequent to the Value Engineering Study the design for the overall project was modified to include additional mitigation features. The following features were added to the project:

- Increase in the number of Oxygen Systems- \$21 million
- Increase in the dimensions of the NSBL&D fish passage - \$21 million
- Construction of a recreational boat ramp in Back River- \$600,000
- Restoration of 35 acres of salt marsh in Disposal Area 1S- \$18 million
- Construction of a raw water impoundment- \$25 million

The methods of construction for the majority of the added features for mitigation are almost identical to the other methods of mitigation that were included during the VE Study. Since there were no VE proposals accepted as a result of the VE Study it was determined that no additional value engineering study was required at that time. Value Engineering Proposals which would result in cost savings to the project will continue to be considered throughout the design and construction of this project. In

addition, USACE guidance requires the project features be re-evaluated during the design phase prior to construction.

**Table 14.0-1: Evaluation of Value Engineering Proposals**

| Proposal No. | Proposal                                                                                                        | Estimated Savings from VE Study | Designer Evaluation                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|--------------|-----------------------------------------------------------------------------------------------------------------|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1            | Consider all cut-off structures/core to be made out of Geo-tubes with a layer of rock over                      | \$0- Not Recommended            | The use of Geo-tubes in high velocity areas and in deep water is not recommended.                                                                                                                                                                                                                                                                                                                                                                       |
| 2            | Make all cut-off walls using rock filled gabions in lieu of rock                                                | \$11,733,000 Cost Added         | Not recommended. Would result in additional cost to the project.                                                                                                                                                                                                                                                                                                                                                                                        |
| 3            | Re-use concrete from Tidegate for core of Sediment Basin Sill                                                   | \$770,493                       | Potential cost savings during PED; however, removal of rebar would have to be added to cost.                                                                                                                                                                                                                                                                                                                                                            |
| 4            | Use sheet pile in lieu of rock at McCoy Cut for construction of Diversion Structure                             | \$16,230,600                    | This evaluation was based on use of 81,000 tons of rock for construction of the diversion structure. After further analysis it was determined that the quantity of rock was overestimated and should only be 2,200 tons, resulting in a cost of \$400,000, which would be less than the estimated cost of the sheet pile. Further design of the diversion structure is planned during PED and alternative construction methodologies will be revisited. |
| 5            | Reclaim rock from New Cut Area above mean high water, for closure structures                                    | \$384,315                       | This proposal is not recommended due to the disruption/destruction of established marsh in this area to gain access to the rock.                                                                                                                                                                                                                                                                                                                        |
| 6            | Use sand from the southern part of 2A for sand fill at Rifle Cut plug                                           | \$4,039                         | This proposal is recommended and should be included in the PED phase of the project.                                                                                                                                                                                                                                                                                                                                                                    |
| 7            | Use precast concrete and "H" piles for closure structures at McCoy Cut Diversion Structure                      | \$16,725,900                    | This is basically an alternative design for the structure discussed in proposal no. 4. The actual quantity of rock to be placed was previously overestimated and would only cost \$400,000, which would be less than the estimated cost of the concrete "H" piles. Further design of the diversion structure is planned during PED and alternative construction methodologies will be revisited.                                                        |
| 8            | Install piping between DO system and river using tunnels to prevent cutting down or disturbing the ground cover | \$106,089                       | Analysis recommends HDPE instead of DIP pipe. HDPE pipe could collapse. Tunnel option would require use of both DIP pipe and HDPE pipe. Not recommended.                                                                                                                                                                                                                                                                                                |

## 15.0 RISK AND UNCERTAINTY

As part of the SHEP Engineering Investigations, uncertainty with predictions, estimates, and assumptions for project design and cost determination, including mitigation planning, were evaluated and potential risks were identified. See **Table 15-1**, on the next two pages, for a summary of SHEP risk and uncertainty discussion.

**Table 15-2** outlines details on risk and uncertainty for possible sea level changes in Savannah Harbor. Analysis and rates are based on EC 1165-2-211; *Water Resource Policies and Authorities Incorporating Sea-Level Change Considerations in Civil Works Programs* dated July 1, 2009.

Table 15-1: SHEP Engineering Investigations Risk and Uncertainty

| Feature                                                                                                   | Risk/Uncertainty Short Term | Risk/Uncertainty Long Term | Methods Employed to Minimize Risk/Uncertainty                                                                                                                                                                                                                                                                                                                                                                                                         | Discussion                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-----------------------------------------------------------------------------------------------------------|-----------------------------|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Salt water Intrusion in the Aquifer                                                                       | Low                         | Moderate                   | Use of well established industry standards for field data collection. Verification of vertical hydraulic conductivity in the field. Extensive field observations. Use of a well accepted and time proven regional flow model developed and approved by USGS. Verification of model results.                                                                                                                                                           | Moderate risk in the long term is not due to the predictive methods employed, but rather uncertainties in the future pumping rate for the City of Savannah, which could have a far greater impact on the aquifer than channel deepening.                                                                                                                                                                                                                                                                                                                                  |
| Ship Simulation                                                                                           | Low                         | Low                        | Model is well established. Has been used extensively for navigation projects worldwide. Calibrated with detailed mariner input and evaluation of recorded data.                                                                                                                                                                                                                                                                                       | There is a low residual risk in the fact that a simulation is not the real world and unforeseen situations not modeled may occur.                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Channel Side Slope Stability                                                                              | Low                         | Low                        | Generally, in the areas of existing shoreline structures, the existing side slope will be maintained by reducing the channel width. Exceptions occur in the meandering lanes and curve wideners. Established well documented models are used to predict side slopes.                                                                                                                                                                                  | Risk and uncertainty are minimized due to the long period of observations of harbor channel conditions, the extensive number of borings that have been drilled, and the use of well established models.                                                                                                                                                                                                                                                                                                                                                                   |
| Relative Sea Level Change (See Table 15-2 for additional details on sea level rise risk and uncertainty.) | Low                         | Moderate                   | There is a great deal of uncertainty about the potential sea level rise over the next 50 to 100 years throughout the scientific community. To deal with these uncertainties, the project was evaluated with a range of sea level rise scenarios. These rates were calculated using the most recent guidance and the recommended methodology.                                                                                                          | Risk and uncertainty are low for project structures and channels. Overall, the functioning of the navigation project is not expected to be impacted significantly due to sea level rise. One area of concern is that freshwater intakes are located close to the use of the last year for determining impacts rather than some point in the future when sea level will impact these areas with or without the project. Although there is a risk of mitigating more than required, the impact on the environment at year one without this mitigation could be significant. |
| Environmental Impacts                                                                                     | Low                         | Low                        | Establishment of predicted environmental impacts are only as good as the predictive models and available data on existing conditions. Extensive modeling with approved models was done to predict these impacts. Extensive data documentation of existing conditions was also collected. Lastly, an extensive post project monitoring plan and adaptive management plan are included in the project to address unforeseen impacts due to the project. | Risks that remain are the predicted impacts of the project may be understated and the project will not adequately mitigate for project construction or that the predicted impacts are overstated and the project will overmitigate for project construction. The long term monitoring and adaptive management reduce this overall risk significantly.                                                                                                                                                                                                                     |
| Hydrodynamic and Water Quality Models                                                                     | Low                         | Low                        | Large sets of data were used for model calibration. Uncertainty analysis was performed by EAC, independent of the model development. Uncertainty analysis results were incorporated into the model grid.                                                                                                                                                                                                                                              | Risks remain with the predictive models, including 1) inaccuracies in predicting salinities and chloride concentrations, particularly in areas where small variations can impact critical habitat for fish or water quality for industrial use 2) inaccuracies in predicting DO, which could lead to ineffective mitigation design. Even with the best data and predictive models, some uncertainties remain in predicted impacts. The post construction monitoring and adaptive management will address these concerns.                                                  |

Continued on next page

Table 15-1: SHEP Engineering Investigations Risk and Uncertainty (Continued)

| Feature                       | Risk/Uncertainty Short Term | Risk/Uncertainty Long Term | Methods Employed to Minimize Risk/Uncertainty                                                                                                                                                                                                                                                                                                                                              | Discussion                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------------------------------|-----------------------------|----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Underground Utility Pipelines | Low                         | Low                        | An inventory was taken of the pipelines underneath the navigation channel. Pipelines were researched to verify their location and ensure that adequate overhead will remain after dredging. Industry input was collected to determine the safest methodology to remove overhead.                                                                                                           | Risk of damages to pipelines that cross the channel is inherent in the dredging and navigation process and slightly increased due to reduced overhead. Risk includes: 1) ships that lose steering capability in the navigation channel may drop and/or drag anchor to maintain position, potentially causing damage in the area of a pipeline crossing; 2) an error in dredge position, meaning dredge could "spud" (20 ton cylindrical tuben used as pivot points for dredge movement) down on top of pipeline crossing. |
| Ship Forces on the Shoreline  | Low                         | Low                        | The study shows the sum of power from all ships to be less in the deepened channel than the existing channel; therefore, bank erosion due to ship wake should not be increased as a result of deepening the channel. Uncertainty in the prediction is low due to use of proven analytical methods and field data collection. Assumptions made about future ship traffic were conservative. | Erosion due to the ship traffic is minimal when compared to coastal wind and wave processes acting on the shoreline. Therefore risk associated with ship traffic wake erosion is low.                                                                                                                                                                                                                                                                                                                                     |
| Bank Erosion Study            | Low                         | Low                        | Studies specifically addressed Fort Pulaski and North Tybee Island. Three separate studies were conducted in those areas. Two by USACE (ERDC and Savannah District) and one by Skidaway Institute of Oceanography (for Fort Pulaski). All reached similar conclusions on the magnitude of shoreline recession.                                                                             | Bank erosion due to ship traffic is much lower than erosion due to other causes. Risk of underestimating erosion due to ship traffic is low relative to impacts of erosion due to other causes. It can be assumed that erosion control measures will be put in place as needed to address this erosion.                                                                                                                                                                                                                   |
| Coastal Erosion Study         | Low                         | Low                        | Coastal models produced similar results to those which have occurred in the historic record. Extensive data is included in the historic record due to extensive records in this area.                                                                                                                                                                                                      | Risk is low for increases in erosion due to channel deepening. Monitoring of the Federal Project will continue and adjustments to the bank reinforcement project will be made if erosion rates increase after deepening.                                                                                                                                                                                                                                                                                                  |
| Sedimentation and Shoaling    | Low                         | Low                        | Previous deepening and widening projects have not resulted in an increase in the overall volume of material shoaling in the harbor. Uncertainty is related to where shoaling will occur in the harbor due to discontinued use of the sediment basin.                                                                                                                                       | Based on the historic records as well as salinity and hydrodynamic models, shoaling locations and volumes have been predicted for the deepened project. If shoaling locations vary from those predicted, the advance maintenance for the project may be adjusted in some areas. Adequate O&M funding will be required to maintain the channel in areas outside of the sediment basin.                                                                                                                                     |
| Cost Risk Analysis            | Low                         | Low                        | A cost risk analysis was performed by the USACE Center of Expertise in the Walla Walla District to support contingency percentages for risk and uncertainty.                                                                                                                                                                                                                               | The risk for unanticipated costs of the project exists, however this risk is considered low due to the high level of design for this feasibility project and the contingencies included in project cost.                                                                                                                                                                                                                                                                                                                  |

Table 15-2: SHEP Engineering Investigations Risk and Uncertainty for Sea Level Rise

| Project Component                            | Year | Low Rate of Sea Level Rise (0.01 ft/yr) |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Intermediate Rate of Sea Level Rise (EC 1105-2-211, Curve 2) |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | High Level of Sea Level Rise (EC 1105-2-211, Curve 3) |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|----------------------------------------------|------|-----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                              |      | SLR (ft)                                | Impacts/Risk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | SLR (ft)                                                     | Impacts/Risk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | SLR (ft)                                              | Impacts/Risk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Dredging, Entrances Channel and Inner Harbor | 1    | 0                                       | Base Condition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 0                                                            | No Change- No Risk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0                                                     | No Change- No Risk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                              | 25   | 0.3                                     | Depth will be relative to MLLW, which is adjusted as sea level rises, gradually the channel will fill in on the bottom, dredging requirements will stay the same. No risk to navigation interests - Low Risk                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.4                                                          | Depth will be relative to MLLW, which is adjusted as sea level rises, gradually the channel will fill in on the bottom, dredging requirements will stay the same. No risk to navigation interests - Low Risk                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.9                                                   | Depth will be relative to MLLW, which is adjusted as sea level rises, gradually the channel will fill in on the bottom, dredging requirements will stay the same. No risk to navigation interests - Low Risk                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                              | 50   | 0.5                                     | Depth will be relative to MLLW, which is adjusted as sea level rises, gradually the channel will fill in on the bottom, dredging requirements will stay the same. No risk to navigation interests - Low Risk                                                                                                                                                                                                                                                                                                                                                                                                                                               | 0.9                                                          | Depth will be relative to MLLW, which is adjusted as sea level rises, gradually the channel will fill in on the bottom, dredging requirements will stay the same. No risk to navigation interests - Low Risk                                                                                                                                                                                                                                                                                                                                                                                                                                               | 2.3                                                   | Depth will be relative to MLLW, which is adjusted as sea level rises, gradually the channel will fill in on the bottom, dredging requirements will stay the same. No risk to navigation interests - Low Risk                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                              | 1    | 0                                       | Base Condition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 0                                                            | No Change- No Risk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 0                                                     | No Change- No Risk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Channel O&M                                  | 25   | 0.3                                     | Depth will be relative to MLLW, which is adjusted as sea level rises, gradually the channel will fill in on the bottom. The volume that fills in as the datum is adjusted would be minimal and would be negligible when compared to annual maintenance dredging quantities. O&M dredging quantities have not previously changed due to changes in channel dimensions. All material entering the harbor from upstream is captured. This will not change, but the location of the shoals may move upstream with the salt water interface - Low Risk                                                                                                          | 0.4                                                          | Depth will be relative to MLLW, which is adjusted as sea level rises, gradually the channel will fill in on the bottom. The volume that fills in as the datum is adjusted would be minimal and would be negligible when compared to annual maintenance dredging quantities. O&M dredging quantities have not previously changed due to changes in channel dimensions. All material entering the harbor from upstream is captured. This will not change, but the location of the shoals may move upstream with the salt water interface - Low Risk                                                                                                          | 0.9                                                   | Depth will be relative to MLLW, which is adjusted as sea level rises, gradually the channel will fill in on the bottom. The volume that fills in as the datum is adjusted would be minimal and would be negligible when compared to annual maintenance dredging quantities. O&M dredging quantities have not previously changed due to changes in channel dimensions. All material entering the harbor from upstream is captured. This will not change, but the location of the shoals may move upstream with the salt water interface. With increases in sea level rise, this would move farther inland - Moderate Risk for Changes in Dredging Locations        |
|                                              | 50   | 0.5                                     | Depth will be relative to MLLW, which is adjusted as sea level rises, gradually the channel will fill in on the bottom. The volume that fills in as the datum is adjusted would be minimal and would be negligible when compared to annual maintenance dredging quantities. O&M dredging quantities have not previously changed due to changes in channel dimensions. All material entering the harbor from upstream is captured. This will not change, but the location of the shoals may move upstream with the salt water interface. With increases in sea level rise, this would move farther inland - Moderate Risk for Changes in Dredging Locations | 0.9                                                          | Depth will be relative to MLLW, which is adjusted as sea level rises, gradually the channel will fill in on the bottom. The volume that fills in as the datum is adjusted would be minimal and would be negligible when compared to annual maintenance dredging quantities. O&M dredging quantities have not previously changed due to changes in channel dimensions. All material entering the harbor from upstream is captured. This will not change, but the location of the shoals may move upstream with the salt water interface. With increases in sea level rise, this would move farther inland - Moderate Risk for Changes in Dredging Locations | 2.3                                                   | Depth will be relative to MLLW, which is adjusted as sea level rises, gradually the channel will fill in on the bottom. The volume that fills in as the datum is adjusted would be minimal and would be negligible when compared to annual maintenance dredging quantities. O&M dredging quantities have not previously changed due to changes in channel dimensions. All material entering the harbor from upstream is captured. This will not change, but the location of the shoals may move upstream with the salt water interface. With increases in sea level rise, this would move farther inland - Moderate Risk for Changes in O&M spoil locations only. |

Continued on next page



Table 15-2: SHEP Engineering Investigations Risk and Uncertainty for Sea Level Rise (Continued)

| Project Component                     | Year | Low Rate of Sea Level Rise (0.01 ft/yr) |                                                                                                                                                                                                                                                                                                                                                              |          | Intermediate Rate of Sea Level Rise (EC 1165-2-211, Curve 2)                                                                                                                                                                                                                                                                                                 |          |                                                                                                                                                                                                                                                                                                                                                              | High Level of Sea Level Rise (EC 1165-2-211, Curve 3) |                                                                                                                                                                                                                                                                                                                                                              |          |
|---------------------------------------|------|-----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
|                                       |      | SLR (ft)                                | Impacts/Risk                                                                                                                                                                                                                                                                                                                                                 | SLR (ft) | Impacts/Risk                                                                                                                                                                                                                                                                                                                                                 | SLR (ft) | Impacts/Risk                                                                                                                                                                                                                                                                                                                                                 | SLR (ft)                                              | Impacts/Risk                                                                                                                                                                                                                                                                                                                                                 | SLR (ft) |
| Mitigation Features (Sills and Plugs) | 1    | 0                                       | Base Condition                                                                                                                                                                                                                                                                                                                                               | 0        | No Change, No Risk                                                                                                                                                                                                                                                                                                                                           | 0        | No Change, No Risk                                                                                                                                                                                                                                                                                                                                           | 0                                                     | No Change, No Risk                                                                                                                                                                                                                                                                                                                                           | 0        |
|                                       | 25   | 0.3                                     | All sills and plugs are designed to tie into the adjacent shoreline and operate under variable water elevations (mean tide range of over 7.0 feet). After 25 years, all plugs would continue to function as designed - Low Risk                                                                                                                              | 0.4      | All sills and plugs are designed to tie into the adjacent shoreline and operate under variable water elevations (mean tide range of over 7.0 feet). After 25 years, all plugs would continue to function as designed - Low Risk                                                                                                                              | 0.9      | All sills and plugs are designed to tie into the adjacent shoreline and operate under variable water elevations (mean tide range of over 7.0 feet). After 25 years, all plugs would continue to function as designed - Low Risk                                                                                                                              | 0.9                                                   | All sills and plugs are designed to tie into the adjacent shoreline and operate under variable water elevations (mean tide range of over 7.0 feet). After 25 years, all plugs would continue to function as designed - Low Risk                                                                                                                              | 0.9      |
|                                       | 50   | 0.5                                     | All sills and plugs are designed to tie into the adjacent shoreline and operate under variable water elevations (mean tide range of over 7.0 feet). After 50 years, all plugs would continue to function as designed - Low Risk                                                                                                                              | 0.9      | All sills and plugs are designed to tie into the adjacent shoreline and operate under variable water elevations (mean tide range of over 7.0 feet). After 50 years, all plugs would continue to function as designed - Low Risk                                                                                                                              | 2.3      | All sills and plugs are designed to tie into the adjacent shoreline and operate under variable water elevations (mean tide range of over 7.0 feet). After 50 years, all plugs would continue to function as designed - Low Risk                                                                                                                              | 2.3                                                   | All sills and plugs are designed to tie into the adjacent shoreline and operate under variable water elevations (mean tide range of over 7.0 feet). After 50 years, all plugs would continue to function as designed - Low Risk                                                                                                                              | 2.3      |
| Mitigation Feature (Channel Dredging) | 1    | 0                                       | Base Condition                                                                                                                                                                                                                                                                                                                                               | 0        | No Change, No Risk                                                                                                                                                                                                                                                                                                                                           | 0        | No Change, No Risk                                                                                                                                                                                                                                                                                                                                           | 0                                                     | No Change, No Risk                                                                                                                                                                                                                                                                                                                                           | 0        |
|                                       | 25   | 0.3                                     | Upstream creeks dredged as part of the overall flow plan are within the banks of the existing marsh. With a sea level rise of 0.3 feet, they would continue to function properly to carry freshwater flow into the Back River/Wildlife Refuge from upstream. Established dredging depth would be relative to MLLW, as adjusted for sea level rise - Low Risk | 0.4      | Upstream creeks dredged as part of the overall flow plan are within the banks of the existing marsh. With a sea level rise of 0.4 feet, they would continue to function properly to carry freshwater flow into the Back River/Wildlife Refuge from upstream. Established dredging depth would be relative to MLLW, as adjusted for sea level rise - Low Risk | 0.9      | Upstream creeks dredged as part of the overall flow plan are within the banks of the existing marsh. With a sea level rise of 0.9 feet, they would continue to function properly to carry freshwater flow into the Back River/Wildlife Refuge from upstream. Established dredging depth would be relative to MLLW, as adjusted for sea level rise - Low Risk | 0.9                                                   | Upstream creeks dredged as part of the overall flow plan are within the banks of the existing marsh. With a sea level rise of 0.9 feet, they would continue to function properly to carry freshwater flow into the Back River/Wildlife Refuge from upstream. Established dredging depth would be relative to MLLW, as adjusted for sea level rise - Low Risk | 0.9      |
|                                       | 50   | 0.5                                     | Upstream creeks dredged as part of the overall flow plan are within the banks of the existing marsh. With a sea level rise of 0.5 feet, they would continue to function properly to carry freshwater flow into the Back River/Wildlife Refuge from upstream. Established dredging depth would be relative to MLLW, as adjusted for sea level rise - Low Risk | 0.9      | Upstream creeks dredged as part of the overall flow plan are within the banks of the existing marsh. With a sea level rise of 0.9 feet, they would continue to function properly to carry freshwater flow into the Back River/Wildlife Refuge from upstream. Established dredging depth would be relative to MLLW, as adjusted for sea level rise - Low Risk | 2.3      | Upstream creeks dredged as part of the overall flow plan are within the banks of the existing marsh. With a sea level rise of 2.3 feet, they would continue to function properly to carry freshwater flow into the Back River/Wildlife Refuge from upstream. Established dredging depth would be relative to MLLW, as adjusted for sea level rise - Low Risk | 2.3                                                   | Upstream creeks dredged as part of the overall flow plan are within the banks of the existing marsh. With a sea level rise of 2.3 feet, they would continue to function properly to carry freshwater flow into the Back River/Wildlife Refuge from upstream. Established dredging depth would be relative to MLLW, as adjusted for sea level rise - Low Risk | 2.3      |

Continued on next page

Table 15-2: SHEP Engineering Investigations Risk and Uncertainty for Sea Level Rise (Continued)

| Project Component                       | Year | Low Rate of Sea Level Rise (0.01 ft/yr)<br>(Historic) |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Intermediate Rate of Sea Level Rise<br>(EC 1165-2-211, Curve 2) |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | High Level of Sea Level Rise<br>(EC 1165-2-211, Curve 3) |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|-----------------------------------------|------|-------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                         |      | SLR (ft)                                              | Impacts/Risk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | SLR (ft)                                                        | Impacts/Risk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | SLR (ft)                                                 | Impacts/Risk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Mitigation of Freshwater Wetland Losses | 1    | 0                                                     | Base Condition- Freshwater wetlands requiring mitigation for 48 project-337 acres; for 47 project-223 acres; for 46 project-201 acres; for 45 project-0 acres (i.e. fully mitigated with flow altering structures). Based on the Corps policy of "no net loss of wetlands" and the Corps' Environmental Operating Principles this would present the lowest risk for environmental impacts. (known condition, lowest risk)                                                                                                                                                                                                                                                                                                                                 | 0                                                               | Base Condition- Freshwater wetlands requiring mitigation for 48 project-337 acres; for 47 project-223 acres; for 46 project-201 acres; for 45 project-0 acres (i.e. fully mitigated with flow altering structures). Based on the Corps policy of "no net loss of wetlands" and the Corps' Environmental Operating Principles this would present the lowest risk for environmental impacts. (known condition, lowest risk)                                                                                                                                                                                                                                                           | 0                                                        | Base Condition- Freshwater wetlands requiring mitigation for 48 project-337 acres; for 47 project-223 acres; for 46 project-201 acres; for 45 project-0 acres (i.e. fully mitigated with flow altering structures). Based on the Corps policy of "no net loss of wetlands" and the Corps' Environmental Operating Principles this would present the lowest risk for environmental impacts. (known condition, lowest risk)                                                                                                                                     |
|                                         | 25   | 0.3                                                   | Freshwater wetlands requiring mitigation for 48 project-240 acres; for 47 project-167 acres; for 46 project-151 acres; for 45 project-0 acres; for 44 project-0 acres (i.e. fully mitigated with flow altering structures). The risk for mitigating the project based on the base condition could result in over-mitigation by compensating for loss of 97 acres (48 project), 56 acres (47 project), 50 acres (46 project), 32 acres (45 project) that may be lost anyway due to salt water intrusion after 25 years. The risk of not mitigating for the base condition would be the temporal loss of wetlands that would not be compensated for. This would not comply with "no net loss of wetlands" and the Corps Environmental Operating Principles. | 0.4                                                             | Freshwater wetlands requiring mitigation for 48 project-116 acres; for 47 project-100 acres; for 45 project-0 acres (i.e. fully mitigated with flow altering structures). The risk for mitigating the project based on the base condition could result in over-mitigation by compensating for loss of 169 acres (48 project), 107 acres (47 project), 101 acres (46 project) that may be lost anyway due to salt water intrusion after 25 years. The risk of not mitigating for the base condition would be the temporal loss of wetlands that would not be compensated for. This would not comply with "no net loss of wetlands" and the Corps Environmental Operating Principles. | 0.9                                                      | Loss of Freshwater Wetlands would be fully mitigated with flow altering structures. The risk for mitigating the project based on the base condition could result in over-mitigation by compensating for loss of up to 337 acres (for the 48 project) that may be lost anyway due to salt water intrusion after 50 years. The risk of not mitigating for the base condition would be the initial loss of wetlands that would not be compensated for. This would not comply with "no net loss of wetlands" and the Corps Environmental Operating Principles.    |
|                                         | 50   | 0.5                                                   | Freshwater wetlands requiring mitigation for 48 project-130 acres; for 47 project-86 acres; for 46 project-69 acres; for 45 project-0 acres (i.e. fully mitigated with flow altering structures). The risk for mitigating the project based on the base condition could result in over-mitigation by compensating for loss of 207 acres (48 project), 137 acres (47 project), 132 acres (46 project), and 32 acres (45 project) that may be lost anyway due to salt water intrusion after 50 years. The risk of not mitigating for the base condition would be the temporal loss of wetlands that would not be compensated for. This would not comply with "no net loss of wetlands" and the Corps Environmental Operating Principles.                    | 0.9                                                             | Loss of Freshwater Wetlands would be fully mitigated with flow altering structures. The risk for mitigating the project based on the base condition could result in over-mitigation by compensating for loss of up to 337 acres (for the 48 project) that may be lost anyway due to salt water intrusion after 50 years. The risk of not mitigating for the base condition would be the temporal loss of wetlands that would not be compensated for. This would not comply with "no net loss of wetlands" and the Corps Environmental Operating Principles.                                                                                                                         | 2.3                                                      | Loss of Freshwater Wetlands would be fully mitigated with flow altering structures. The risk for mitigating the project based on the base condition could result in over-mitigation by compensating for loss of up to 337 acres (for the 48 project) that would be lost anyway due to salt water intrusion after 50 years. The risk of not mitigating for the base condition would be the temporal loss of wetlands that would not be compensated for. This would not comply with "no net loss of wetlands" and the Corps Environmental Operating Principles. |

Continued on next page

Table 15-2: SHEP Engineering Investigations Risk and Uncertainty for Sea Level Rise (Continued)

| Project Component | Low Rate of Sea Level Rise (0.01 ft/yr) (Historic) |          | Intermediate Rate of Sea Level Rise (EC 1165-2-211, Curve 2)                                                                    |          | High Level of Sea Level Rise (EC 1165-2-211, Curve 3)                                                                                                                                                                 |          |                                                                                                                                                                                                                                                                                                                             |
|-------------------|----------------------------------------------------|----------|---------------------------------------------------------------------------------------------------------------------------------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                   | Year                                               | SLR (ft) | Impacts/Risk                                                                                                                    | SLR (ft) | Impacts/Risk                                                                                                                                                                                                          | SLR (ft) | Impacts/Risk                                                                                                                                                                                                                                                                                                                |
| Upstream Channels | 1                                                  | 0        | Base Condition- No significant impact to City of Savannah Water Supply                                                          | 0        | No Change- No Risk                                                                                                                                                                                                    | 0        | No Change- No Risk                                                                                                                                                                                                                                                                                                          |
|                   | 25                                                 | 0.3      | Moderate impacts to City water intake with or without the project due to further salt water intrusion into the Savannah Harbor. | 0.4      | Moderate impacts to City water intake with or without the project due to further salt water intrusion into the Savannah Harbor. Relocation of the water intake may be necessary.                                      | 0.9      | Significant impacts to City water intake with or without the project due to salt water intrusion into the upper reaches of Savannah Harbor and the Savannah River. Relocation of the water intake would be necessary.                                                                                                       |
|                   | 50                                                 | 0.5      | Moderate impacts to City water intake with or without the project due to further salt water intrusion into the Savannah Harbor. | 0.9      | Significant impacts to City water intake with or without the project due to salt water intrusion into the upper reaches of Savannah Harbor and the Savannah River. Relocation of the water intake would be necessary. | 2.3      | Significant impacts to City water intake with or without the project due to salt water intrusion into the upper reaches of Savannah Harbor and the Savannah River. Relocation of the water intake would be necessary. Moderate risk that project funds intake relocation when sea level rise would require same relocation. |

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# **GENERAL RE-EVALUATION REPORT**

## **APPENDIX C: ENGINEERING**

**SAVANNAH HARBOR EXPANSION PROJECT**

Chatham County, Georgia and Jasper County, South Carolina

**January 2012**

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### **ATTACHMENT 1**

Channel Design Drawings and  
Typical Sections



**US Army Corps  
of Engineers**  
*Savannah District  
South Atlantic Division*









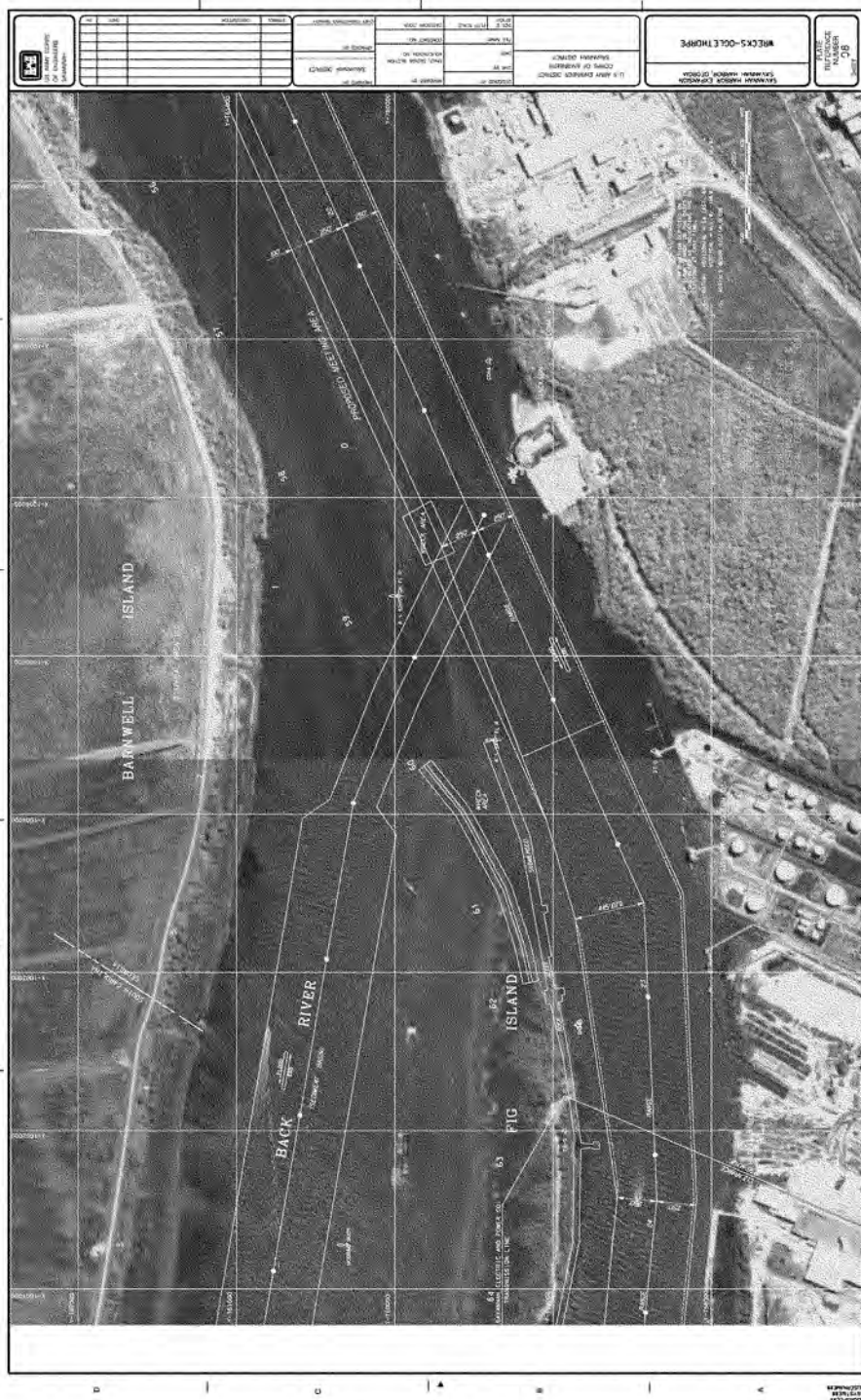






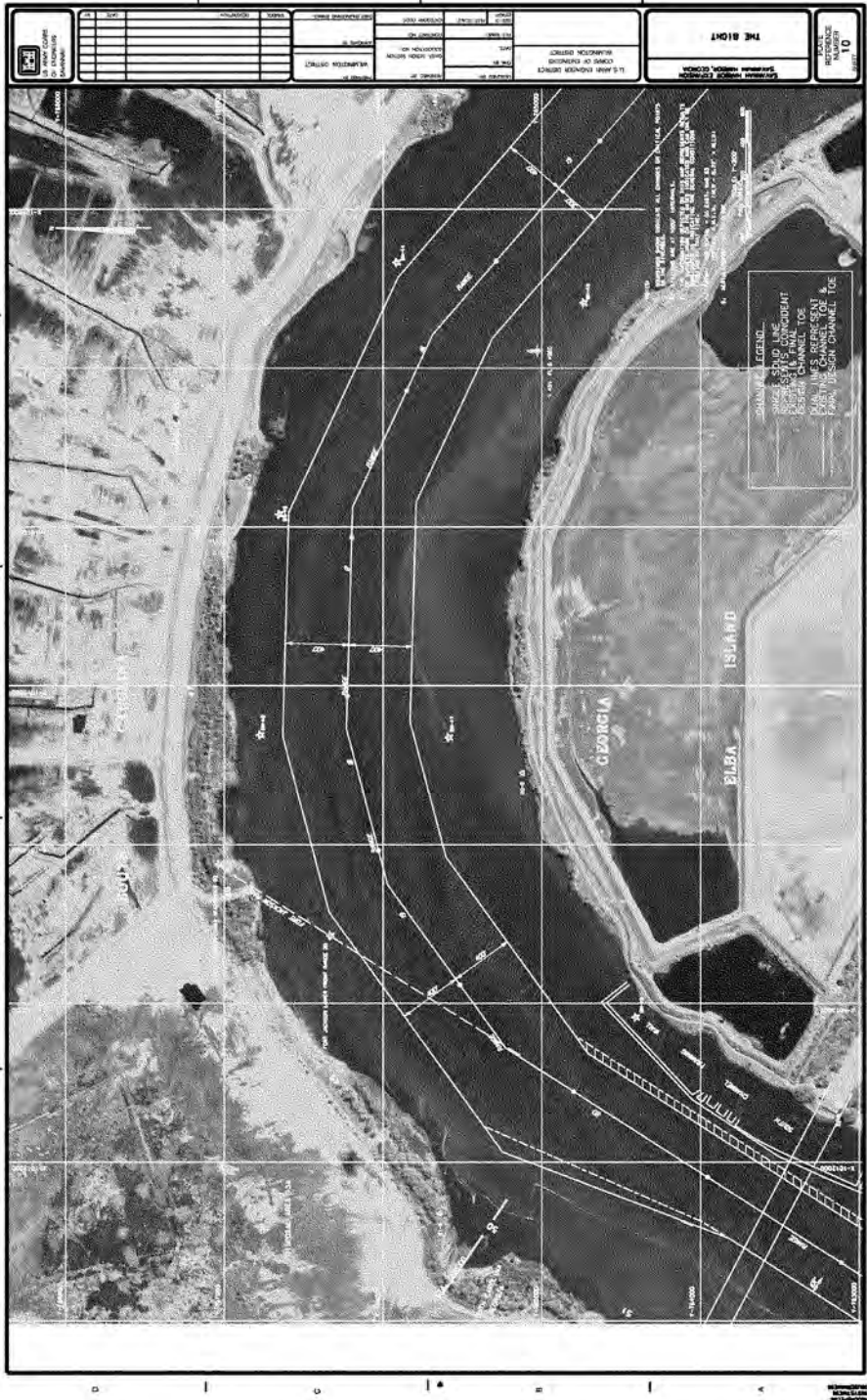




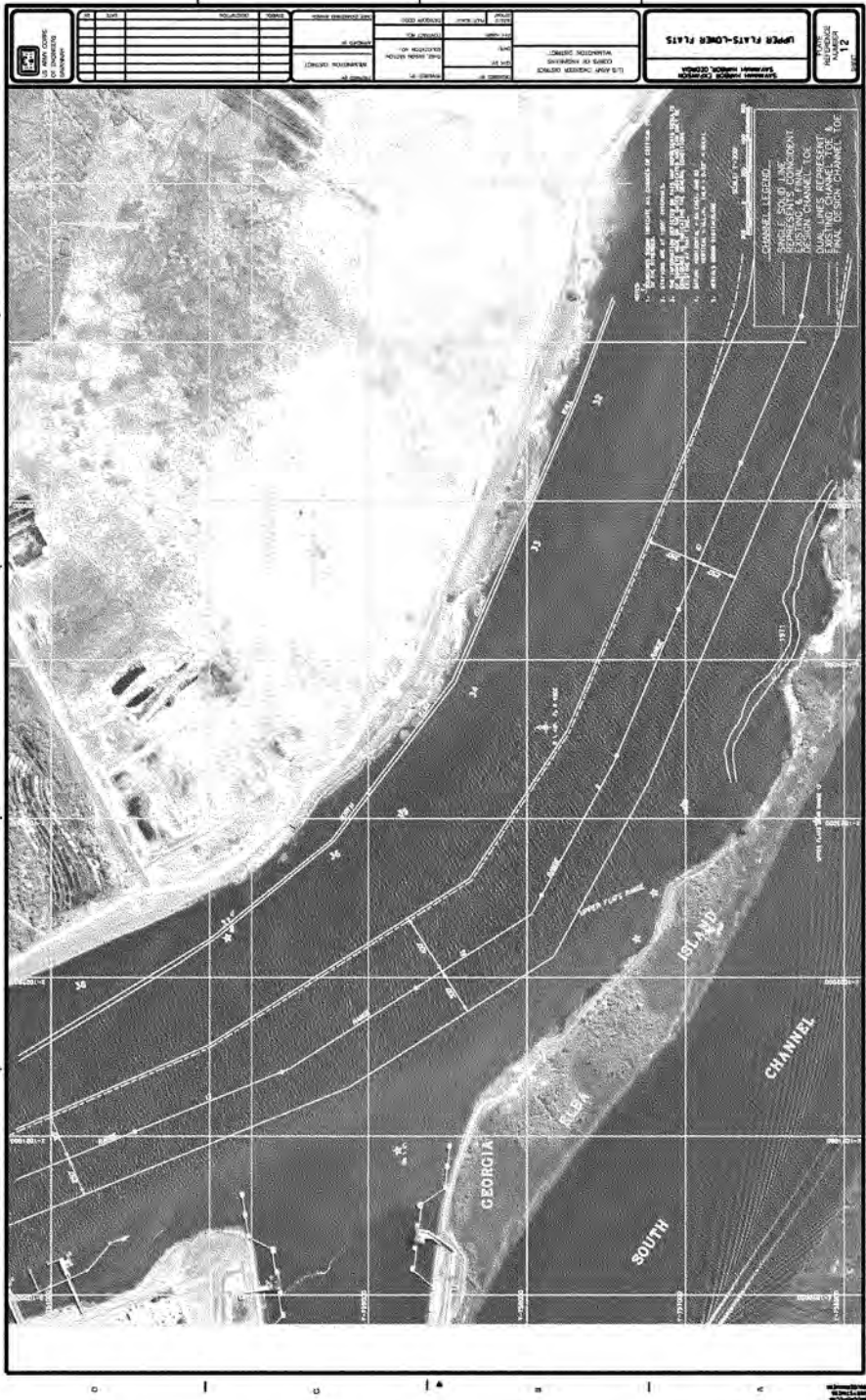




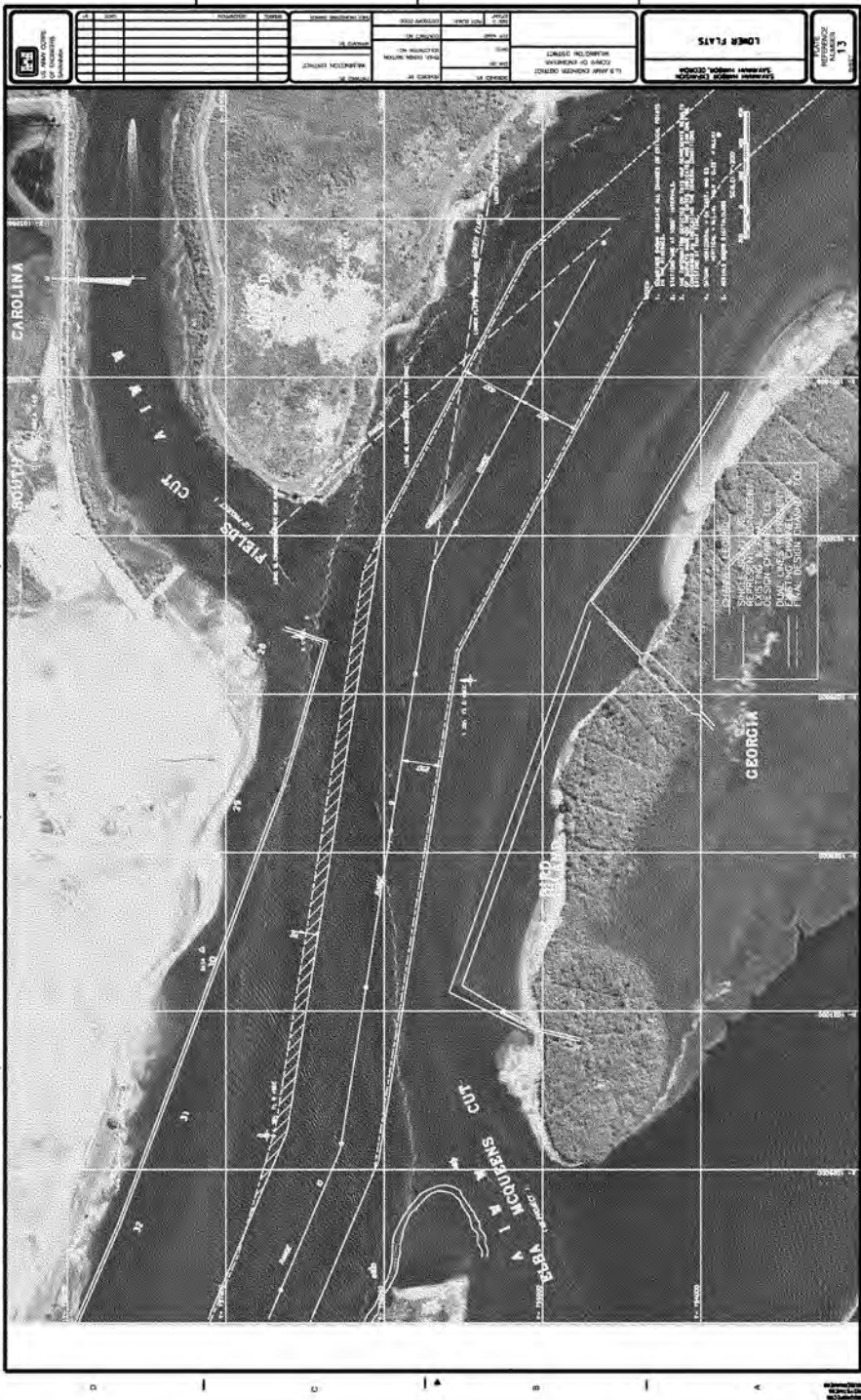






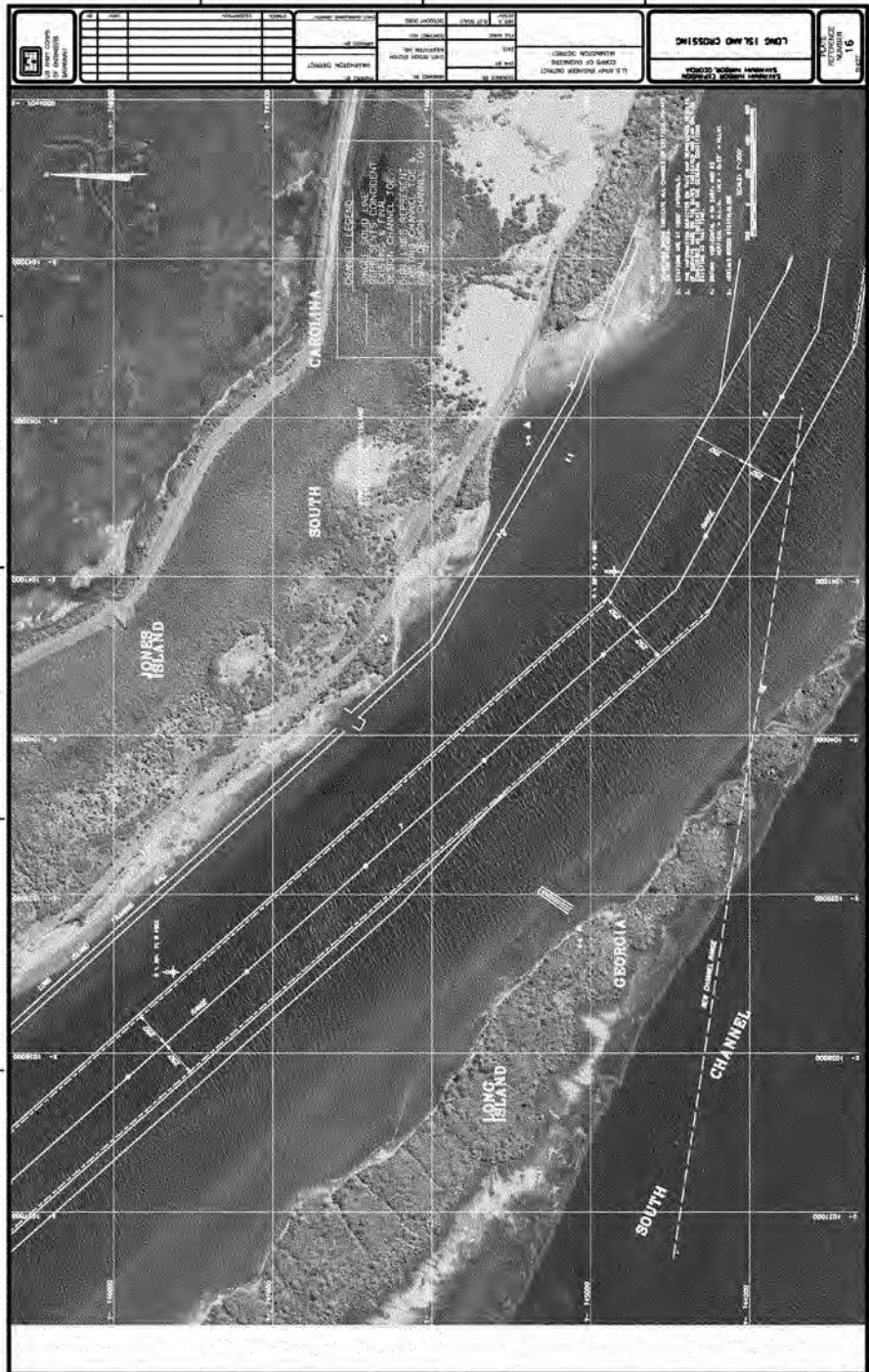














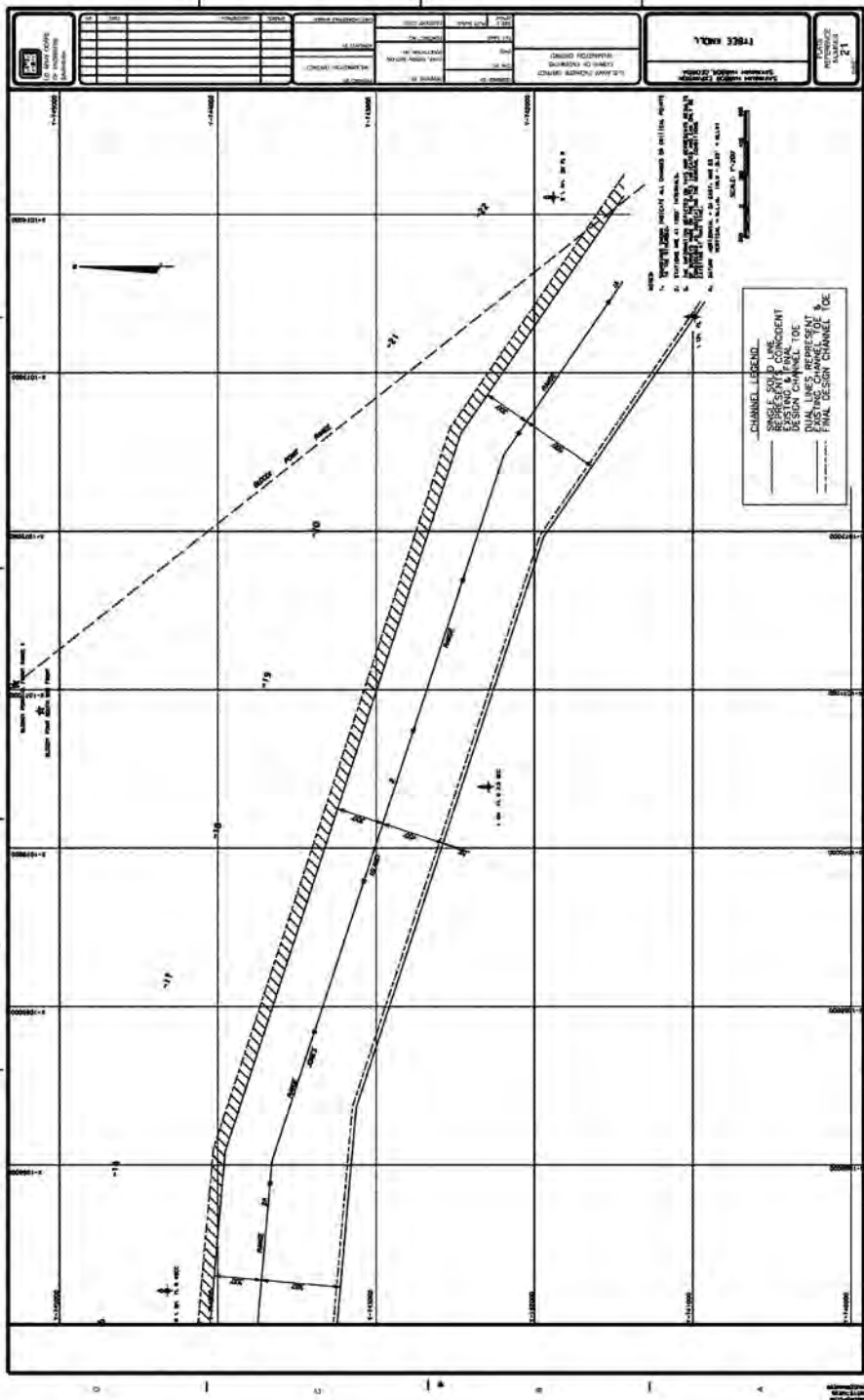




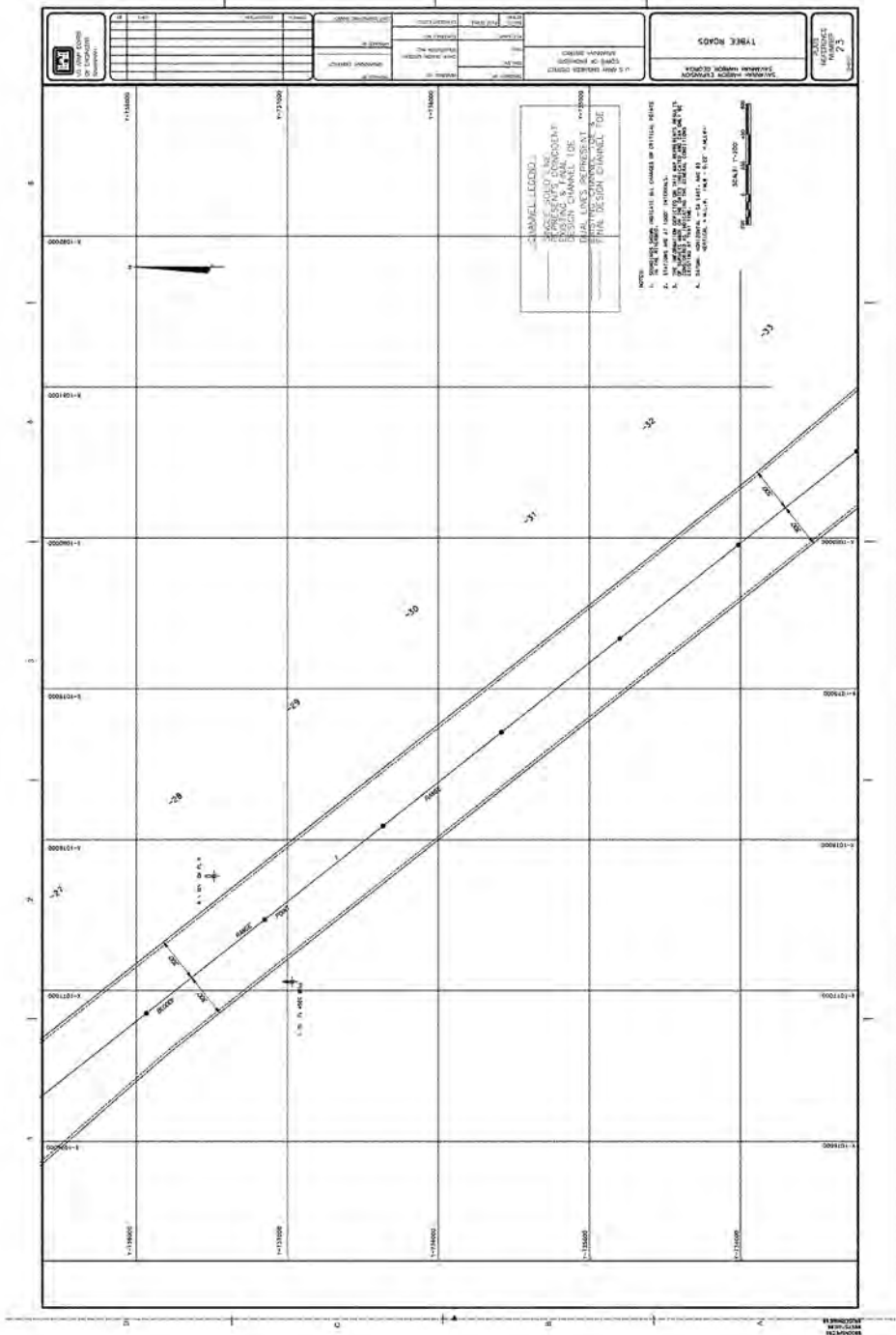


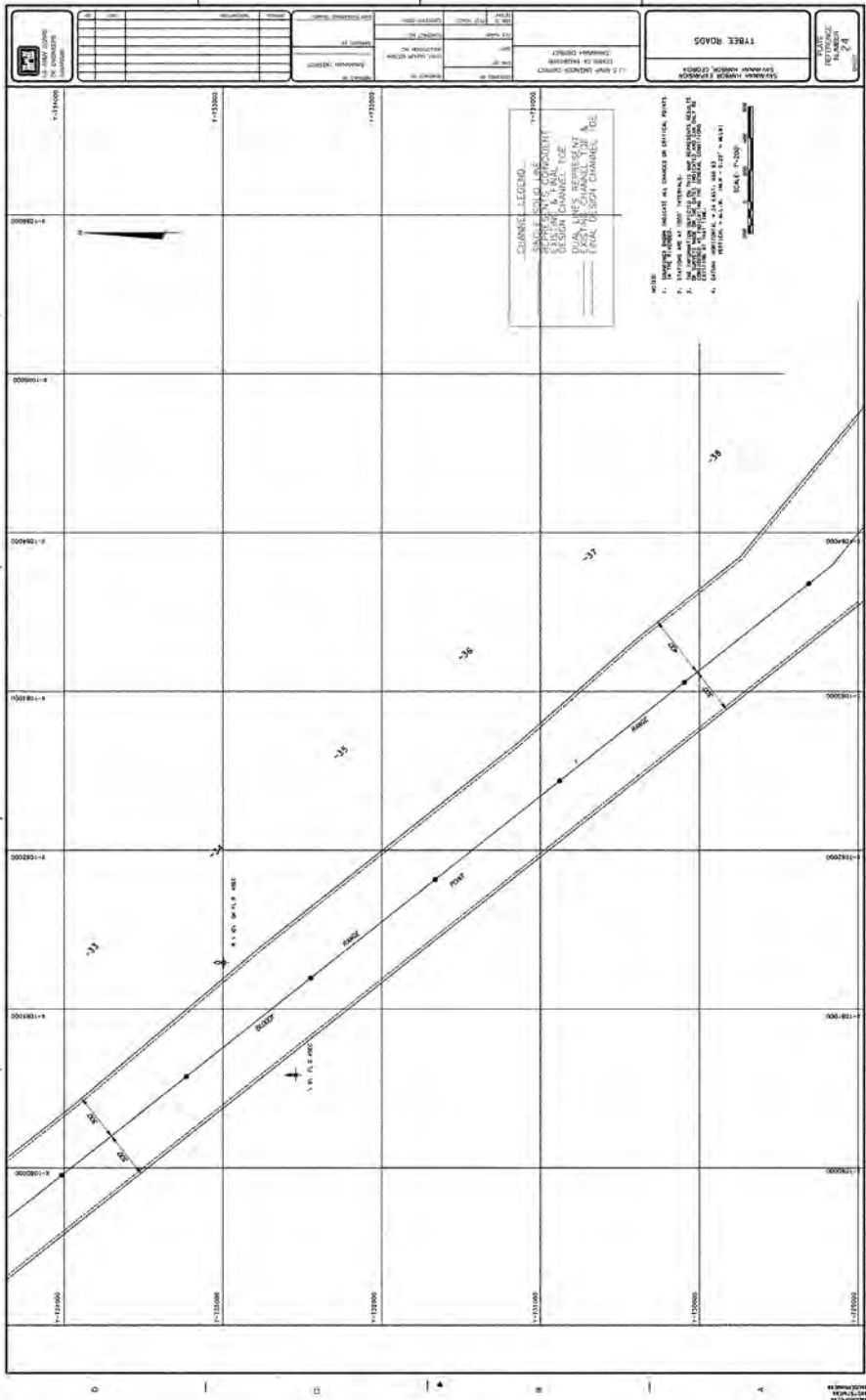


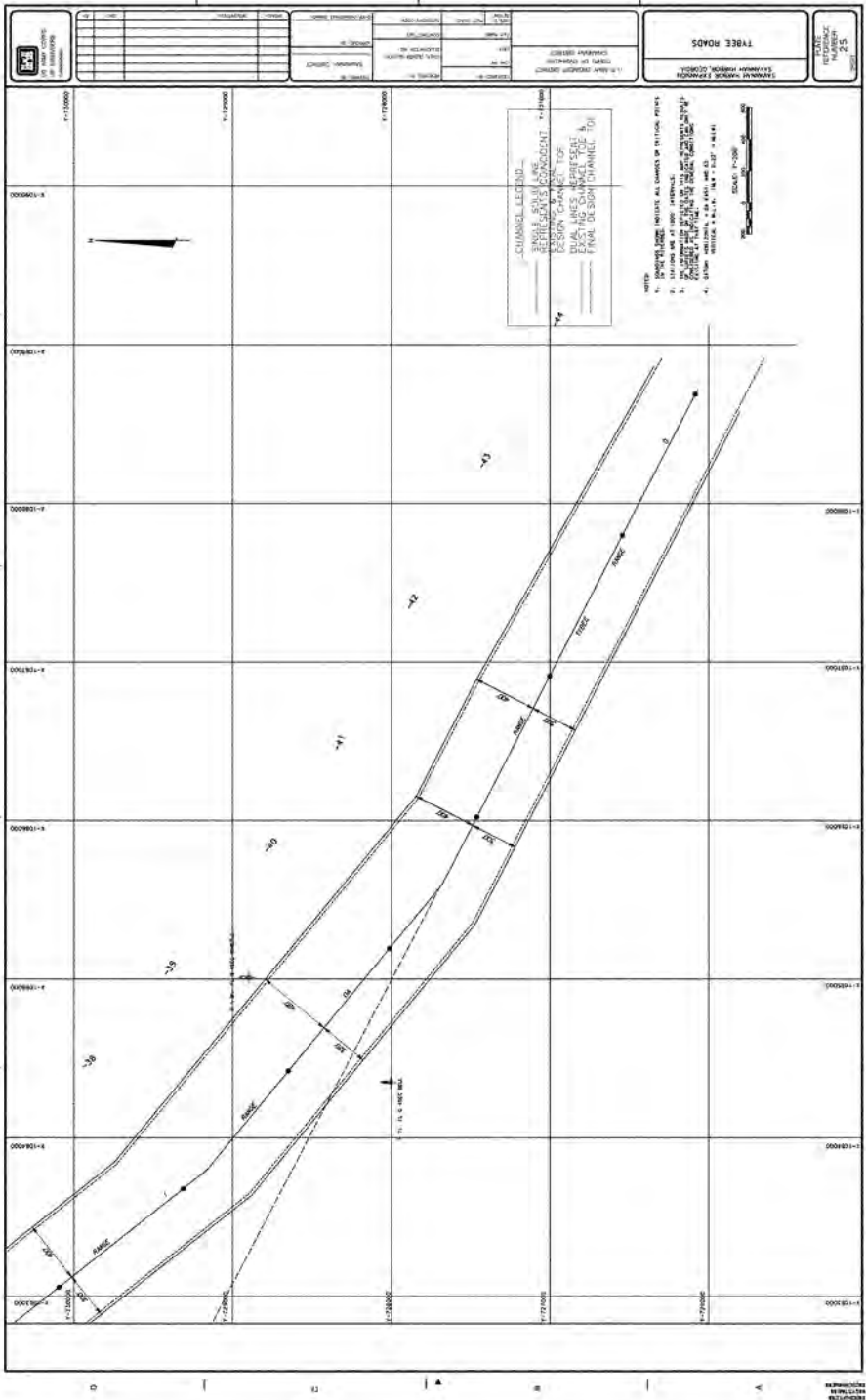


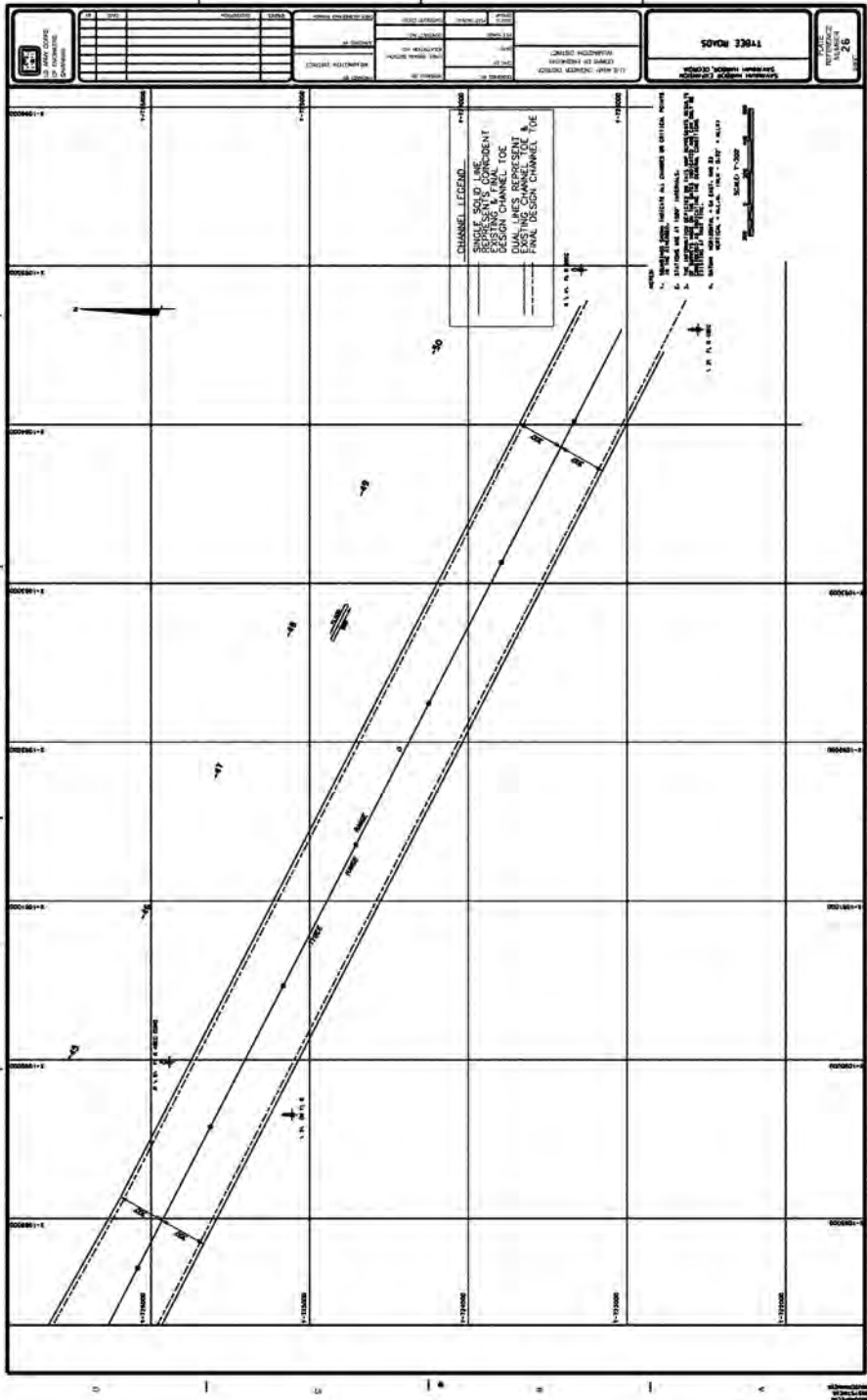


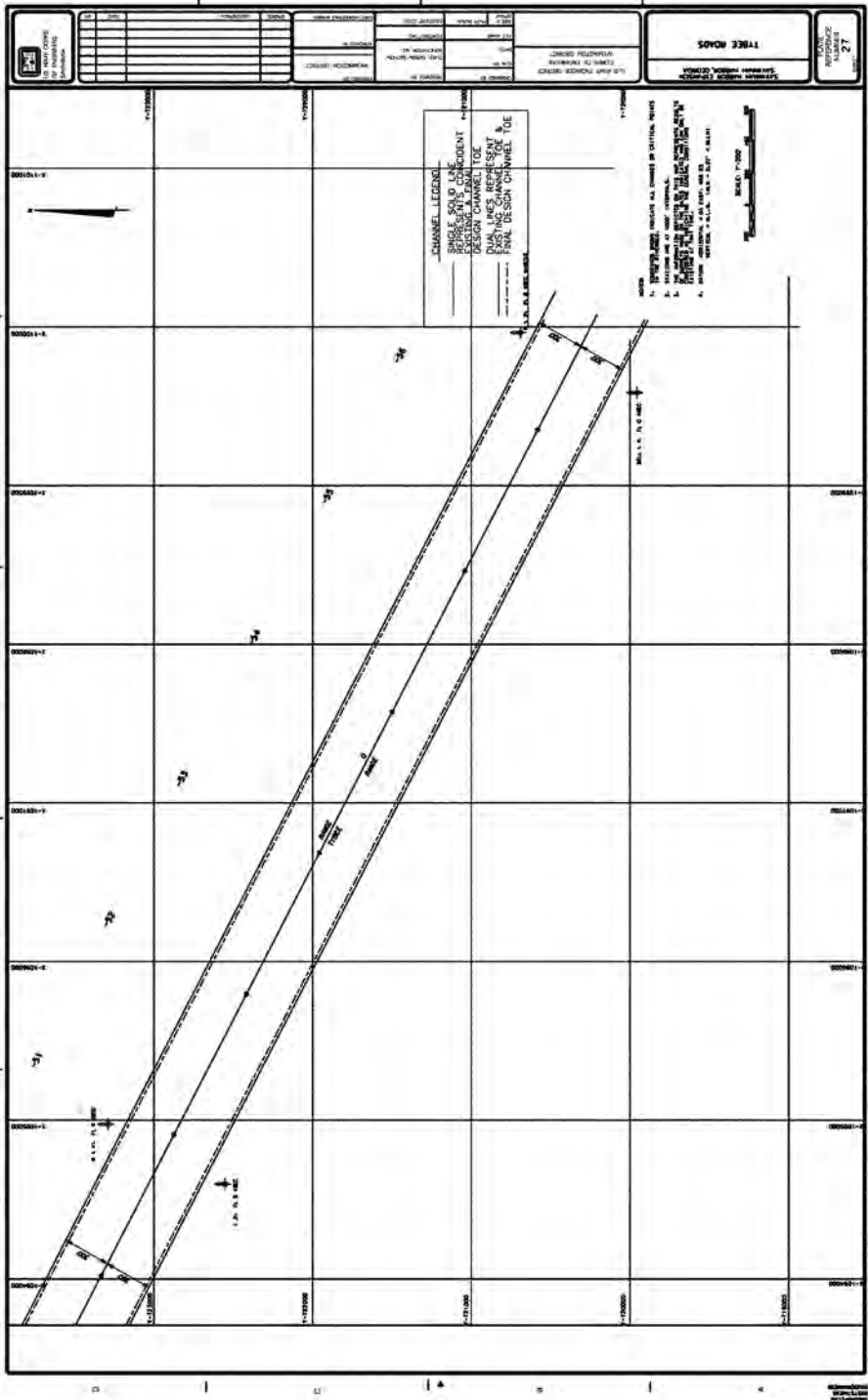


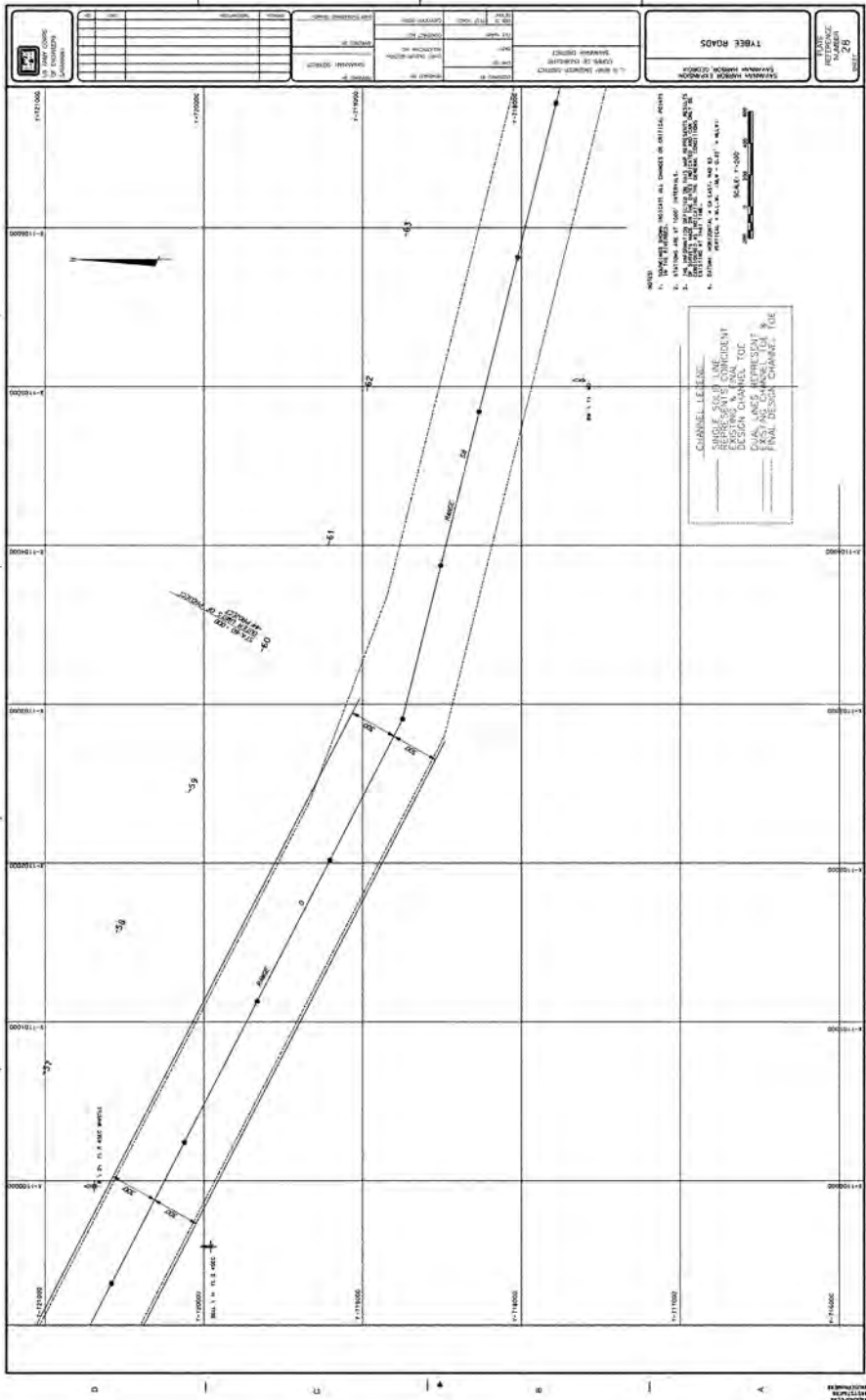




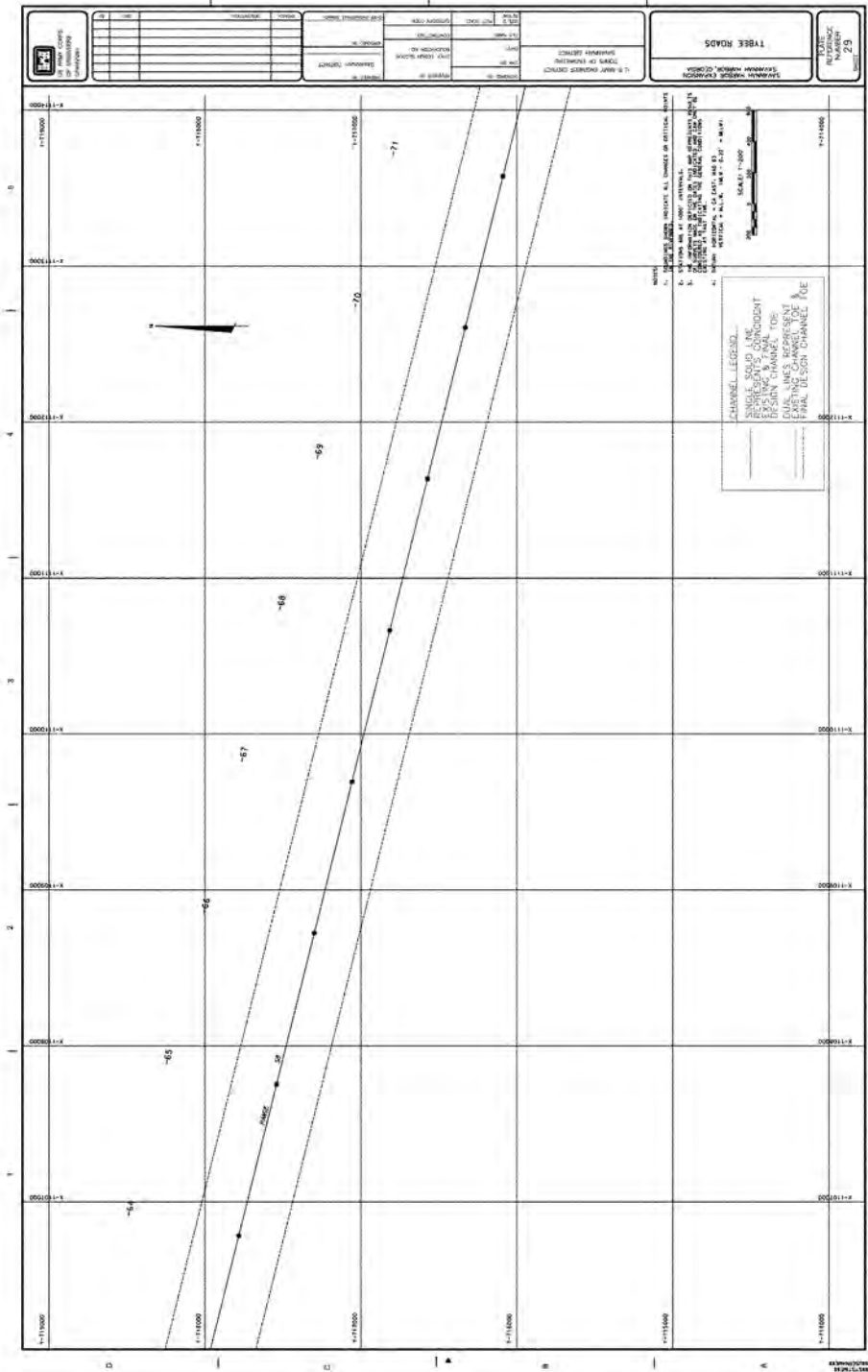


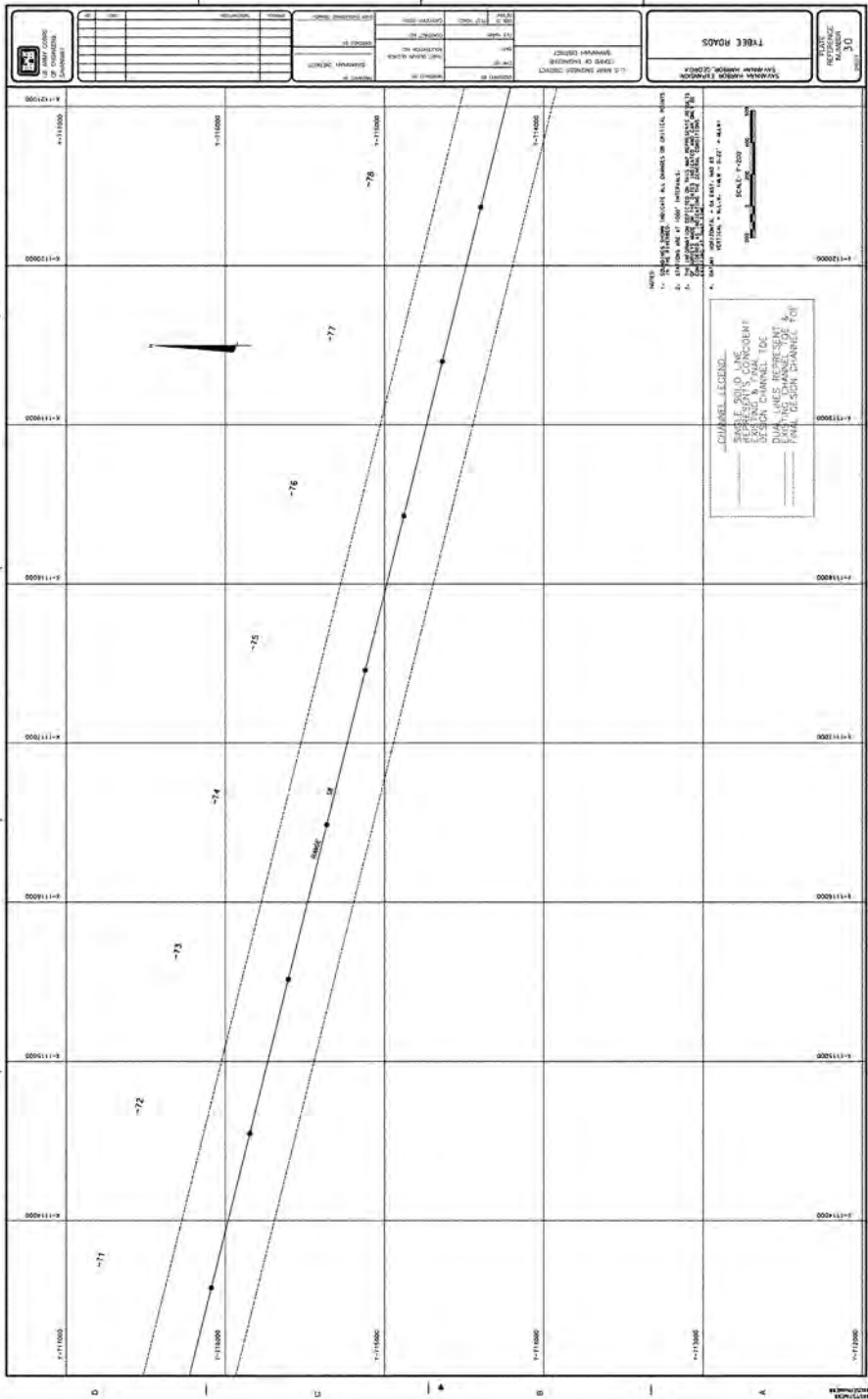


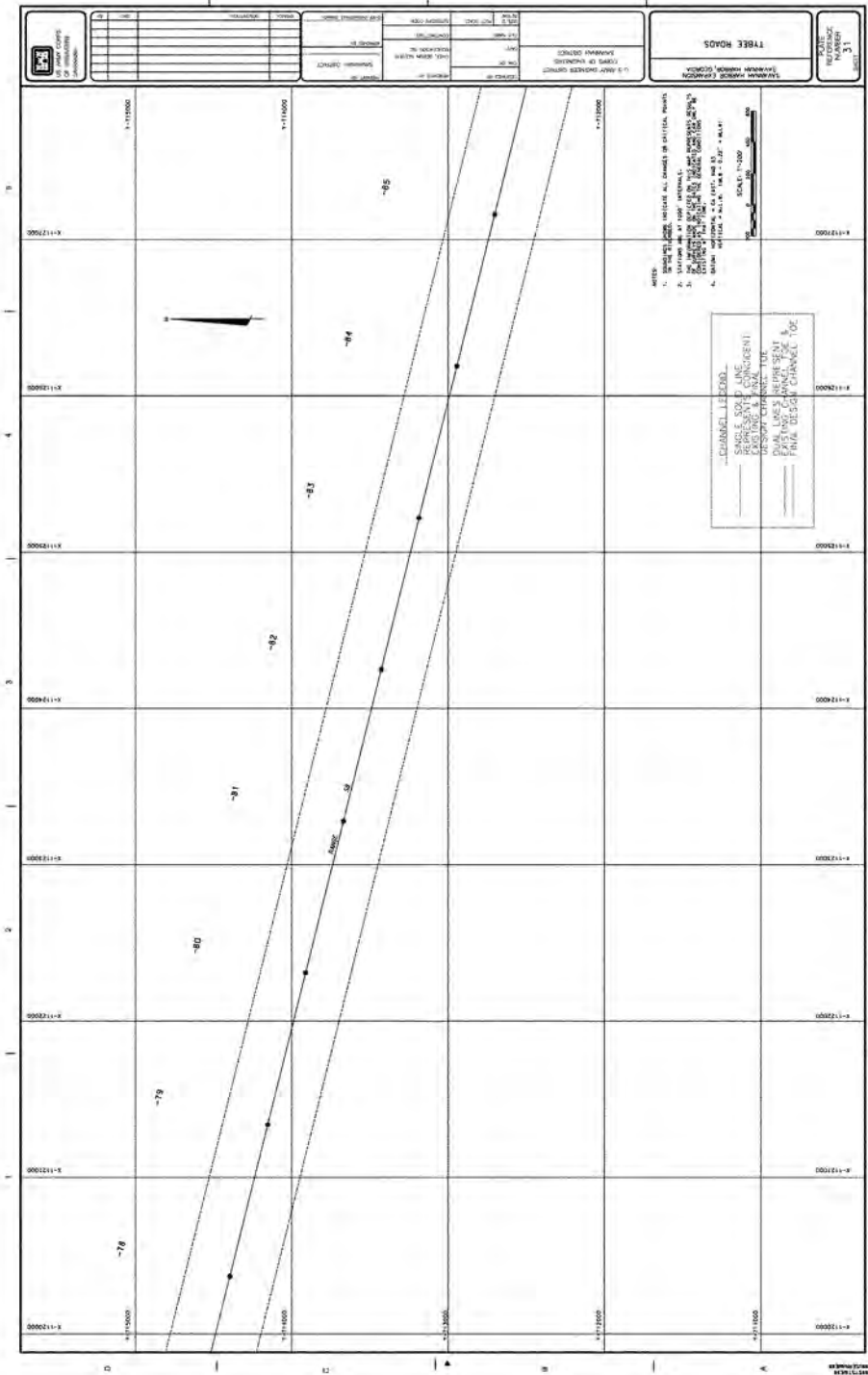


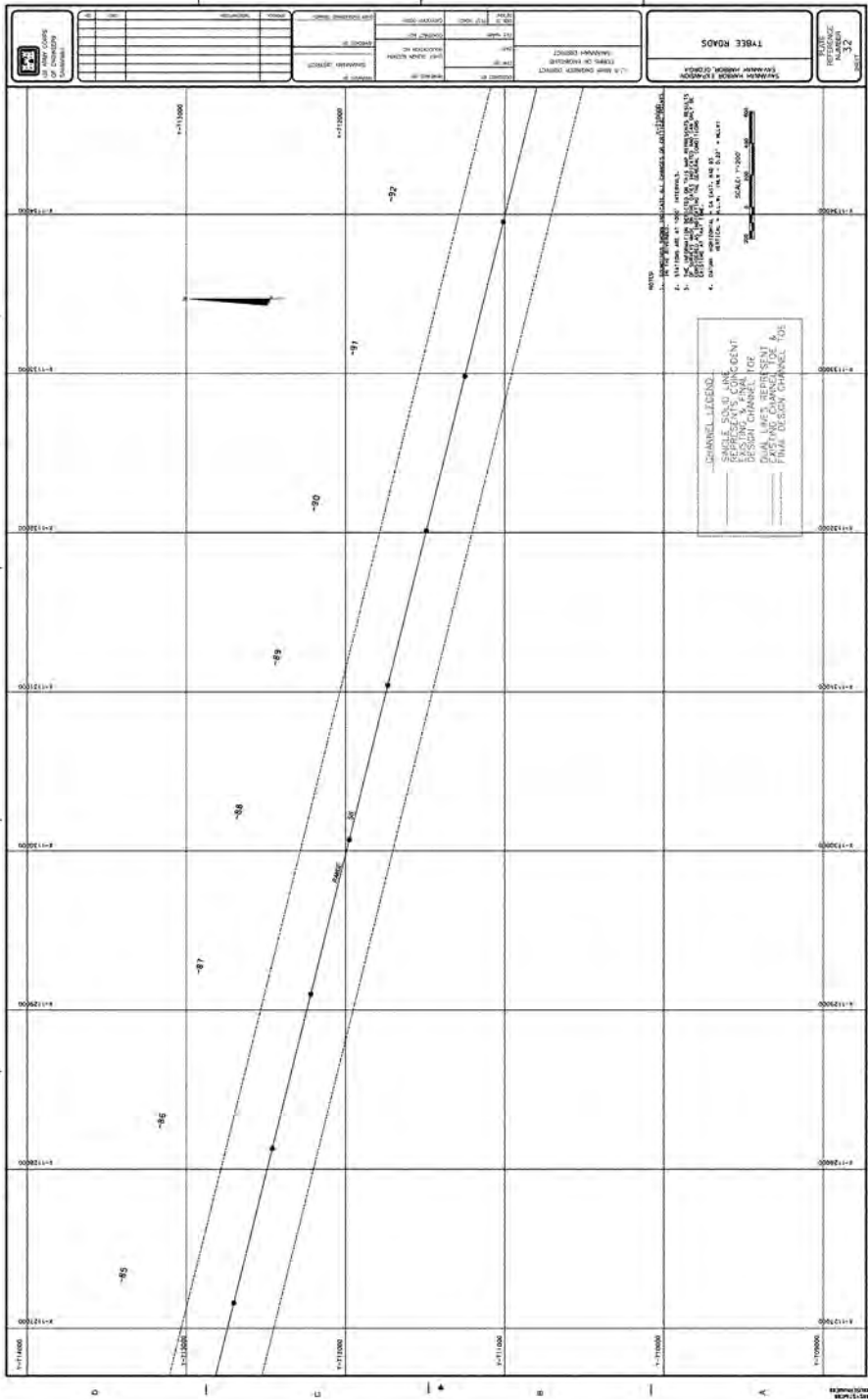


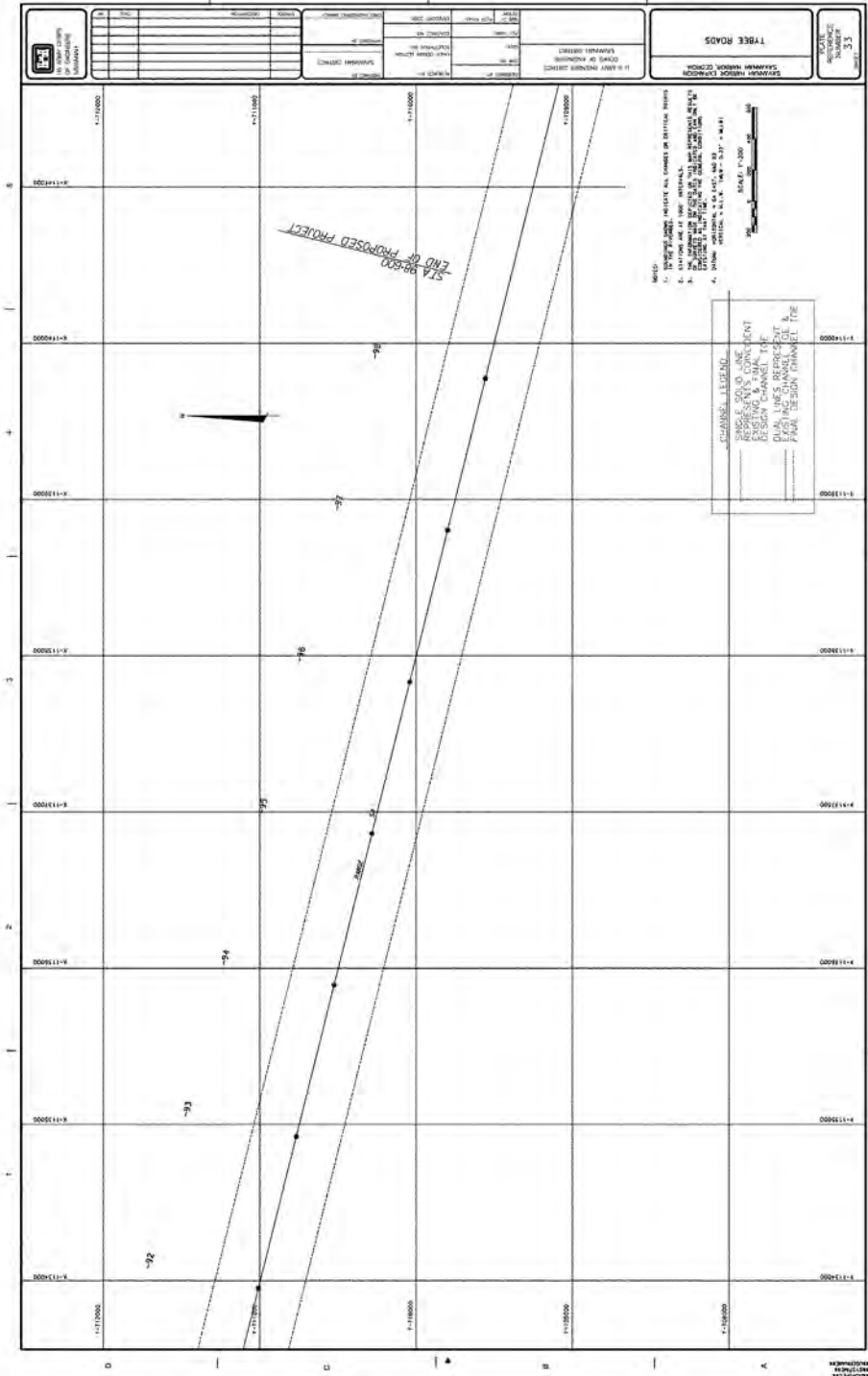


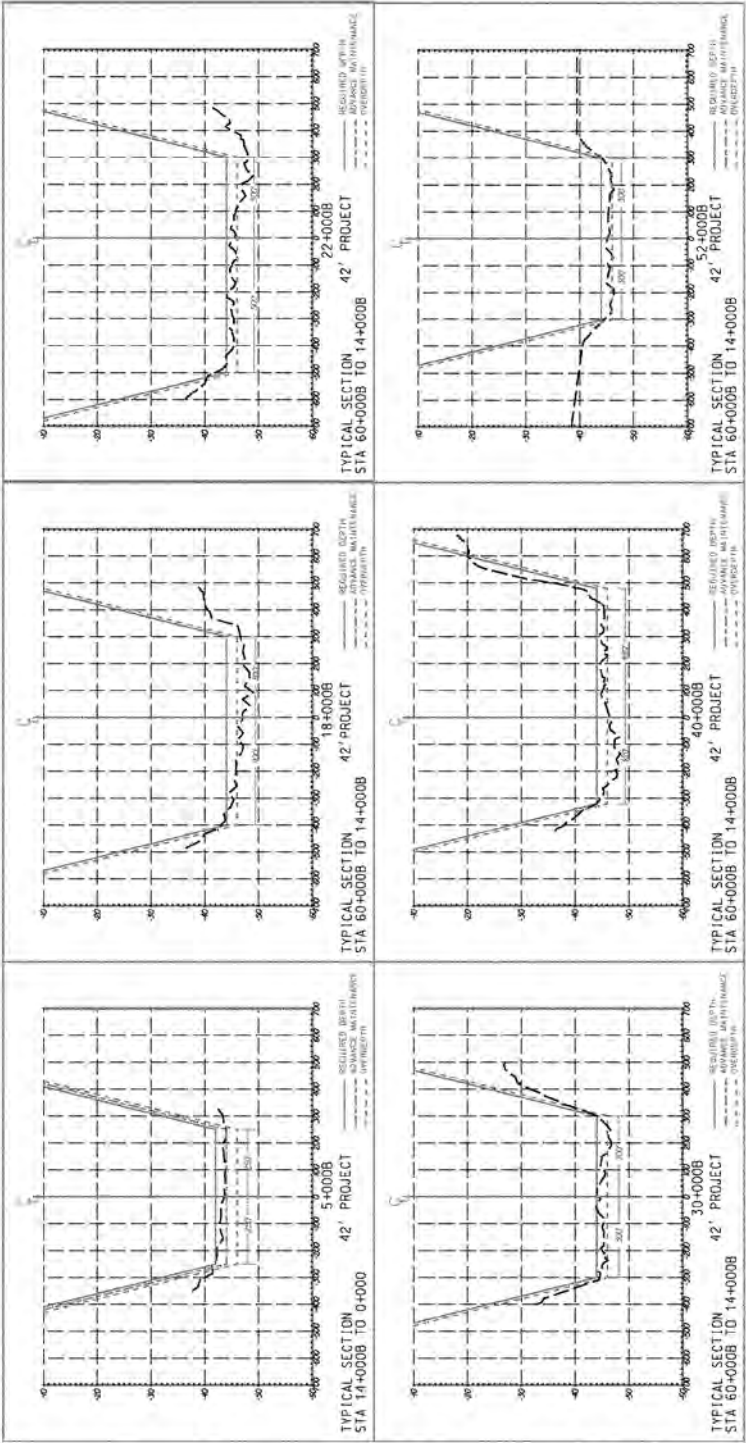




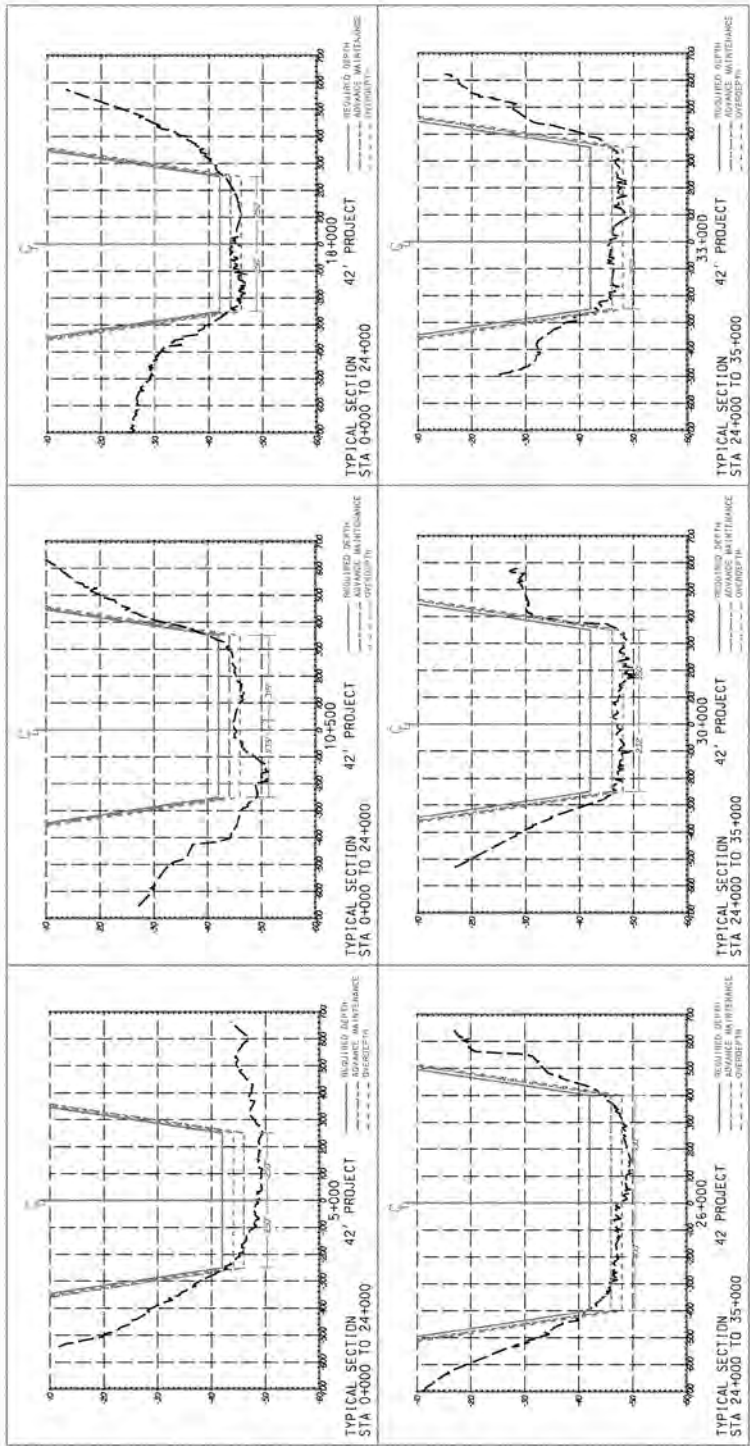




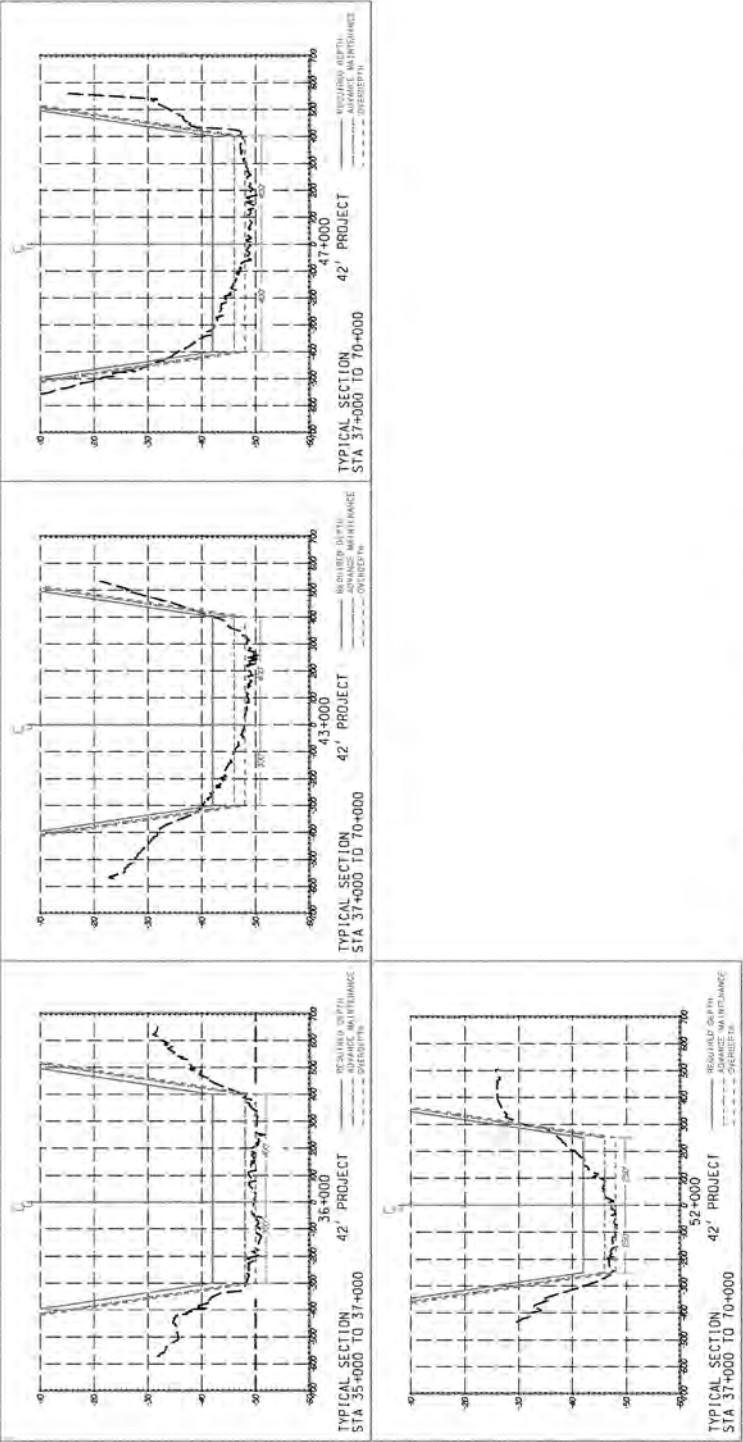




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CURRENTLY AUTHORIZED PROJECT  
STATIONS 5+000B TO 52+000B

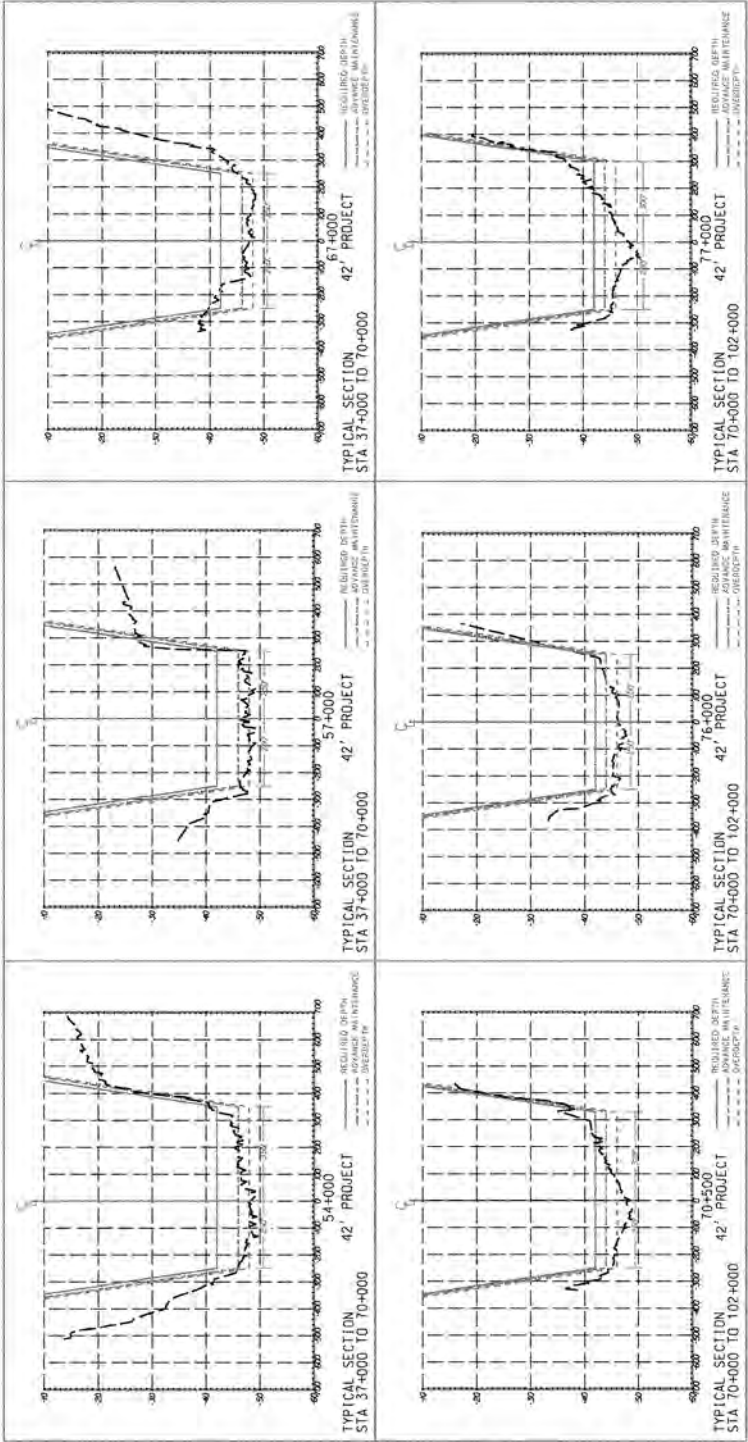


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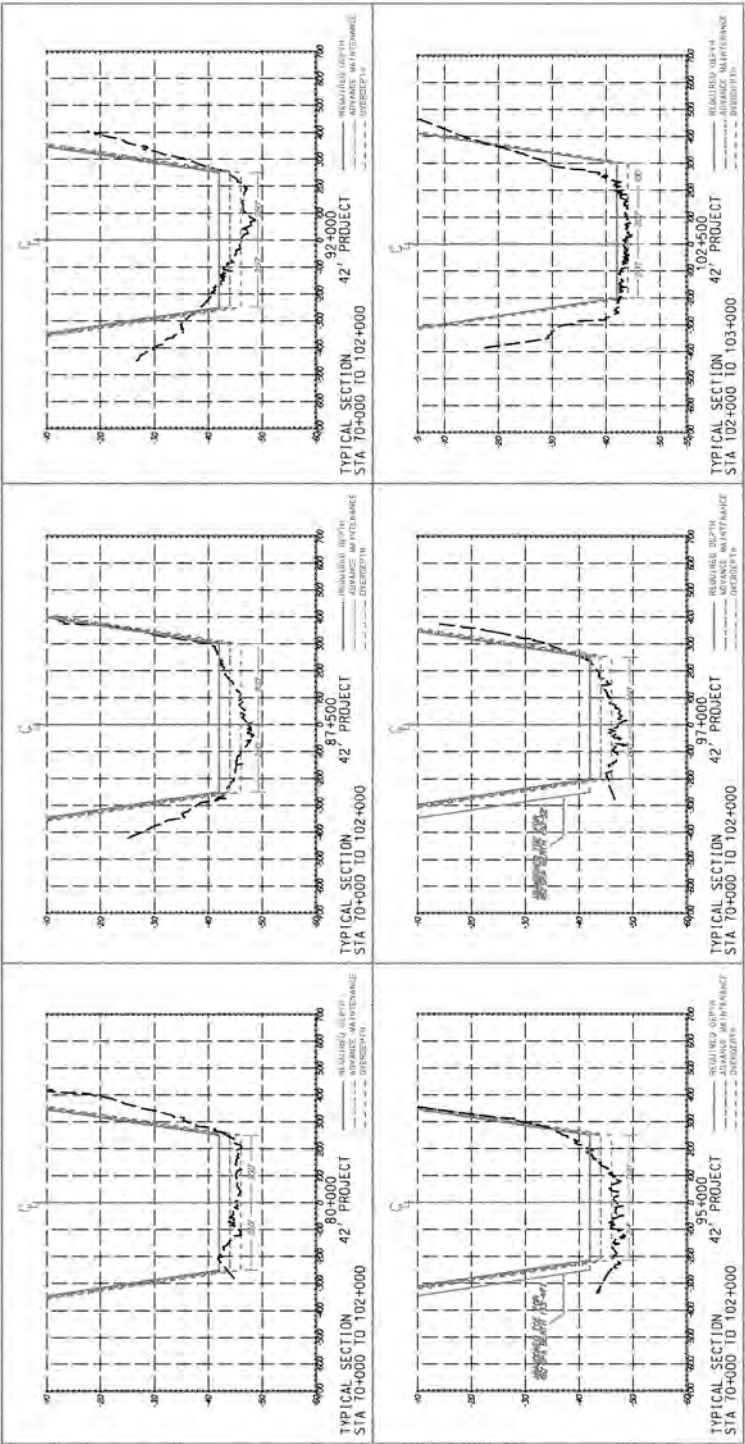


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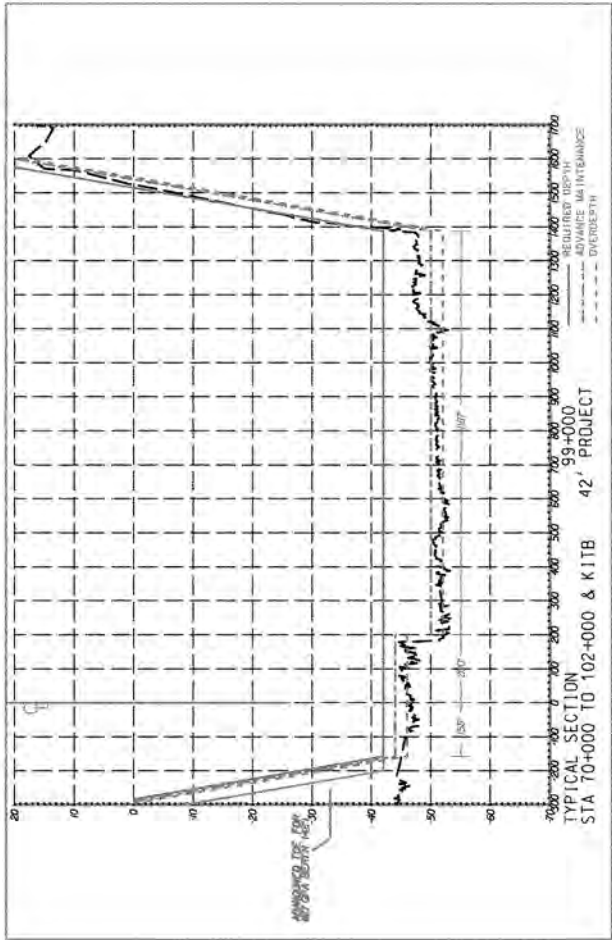




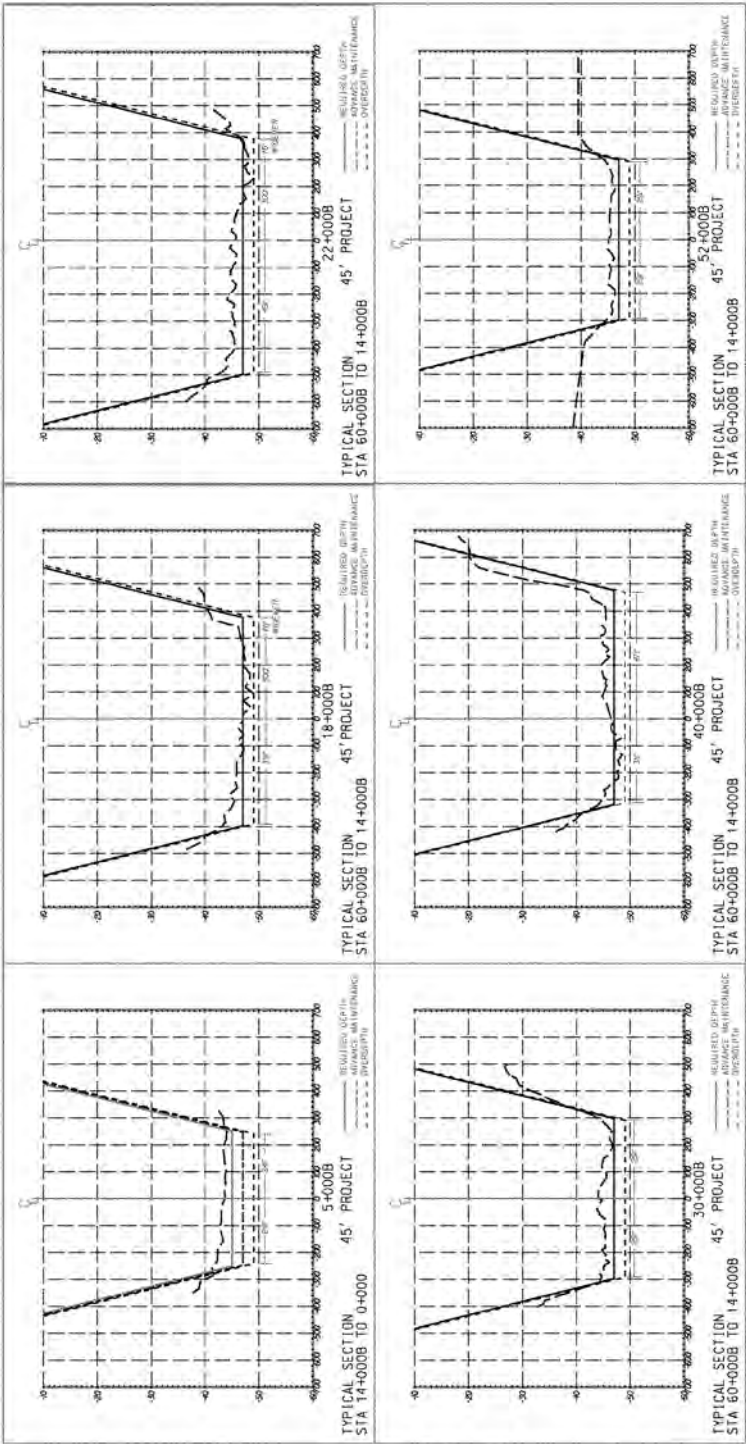
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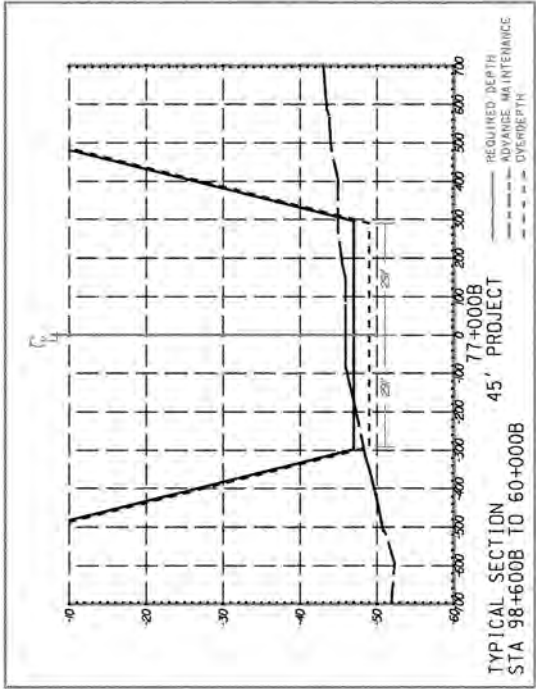
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CURRENTLY AUTHORIZED PROJECT  
STATIONS 80+000 TO 102+500



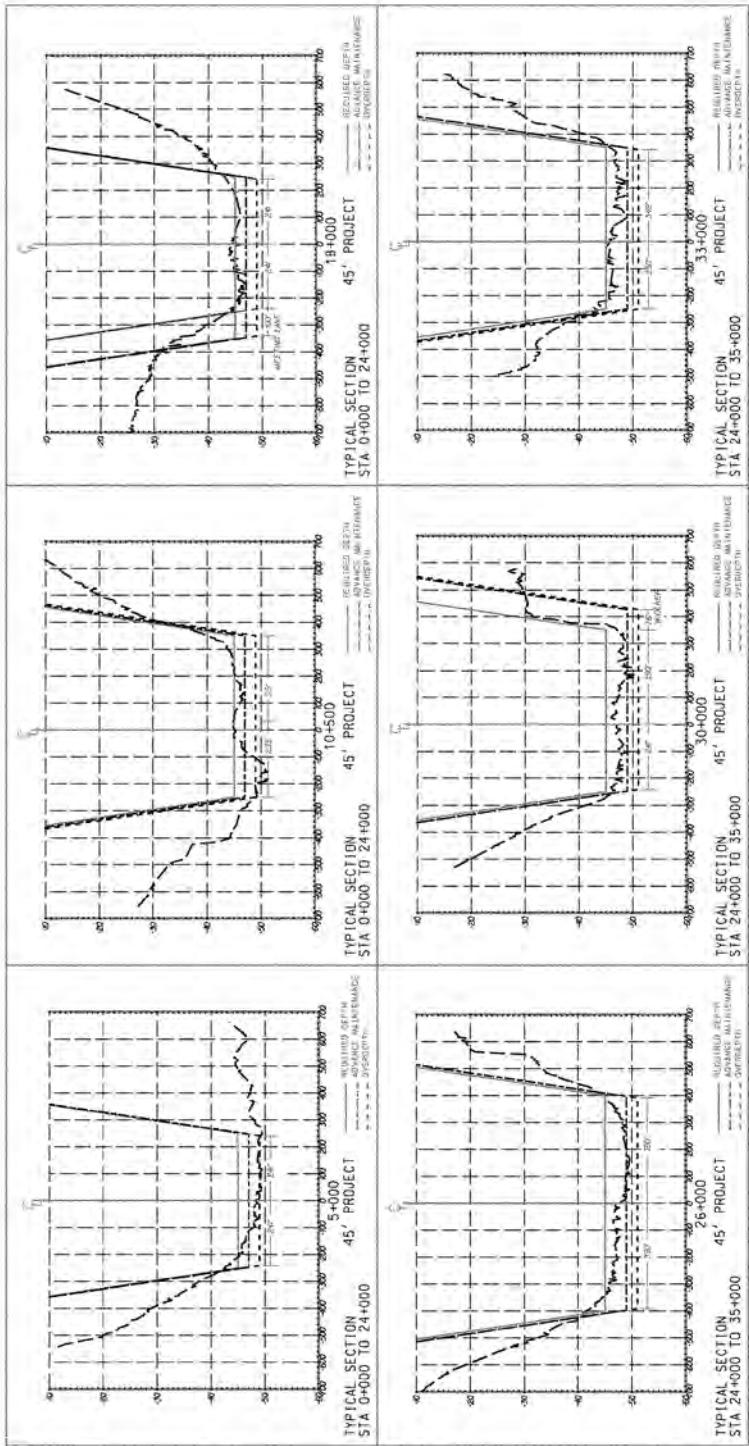
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CURRENTLY AUTHORIZED PROJECT  
KINGS ISLAND TURNING BASIN



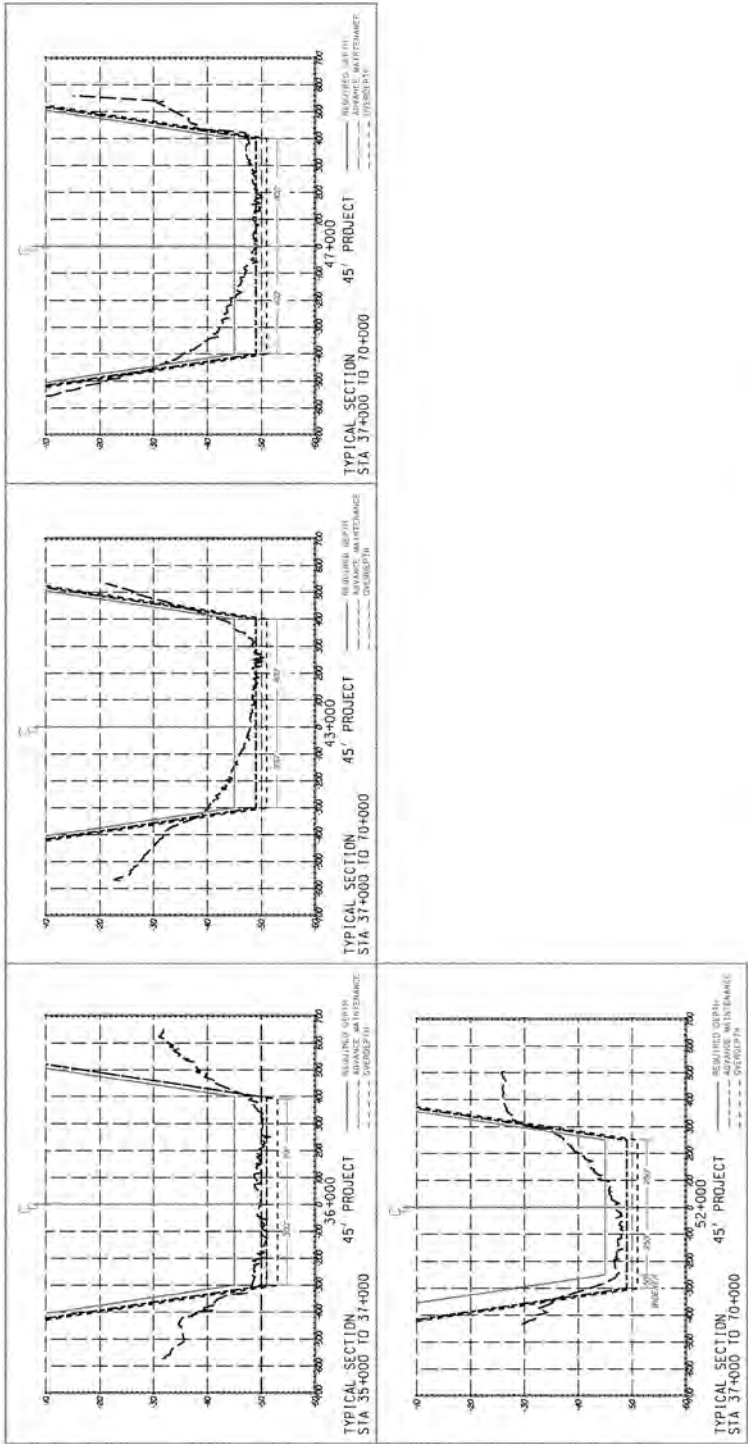
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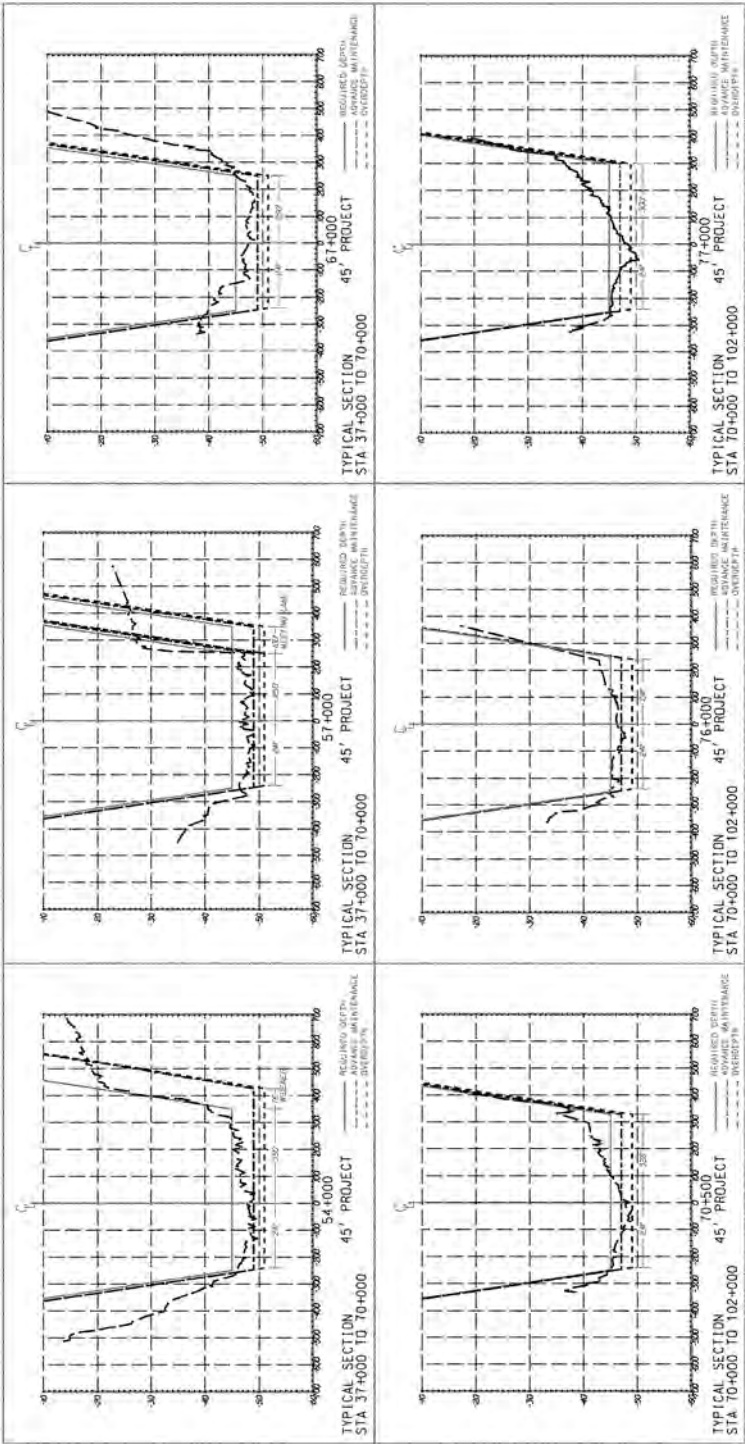
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TYPICAL SECTIONS (LOOKING UPSTREAM)  
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STATIONS 5+000 TO 33+000

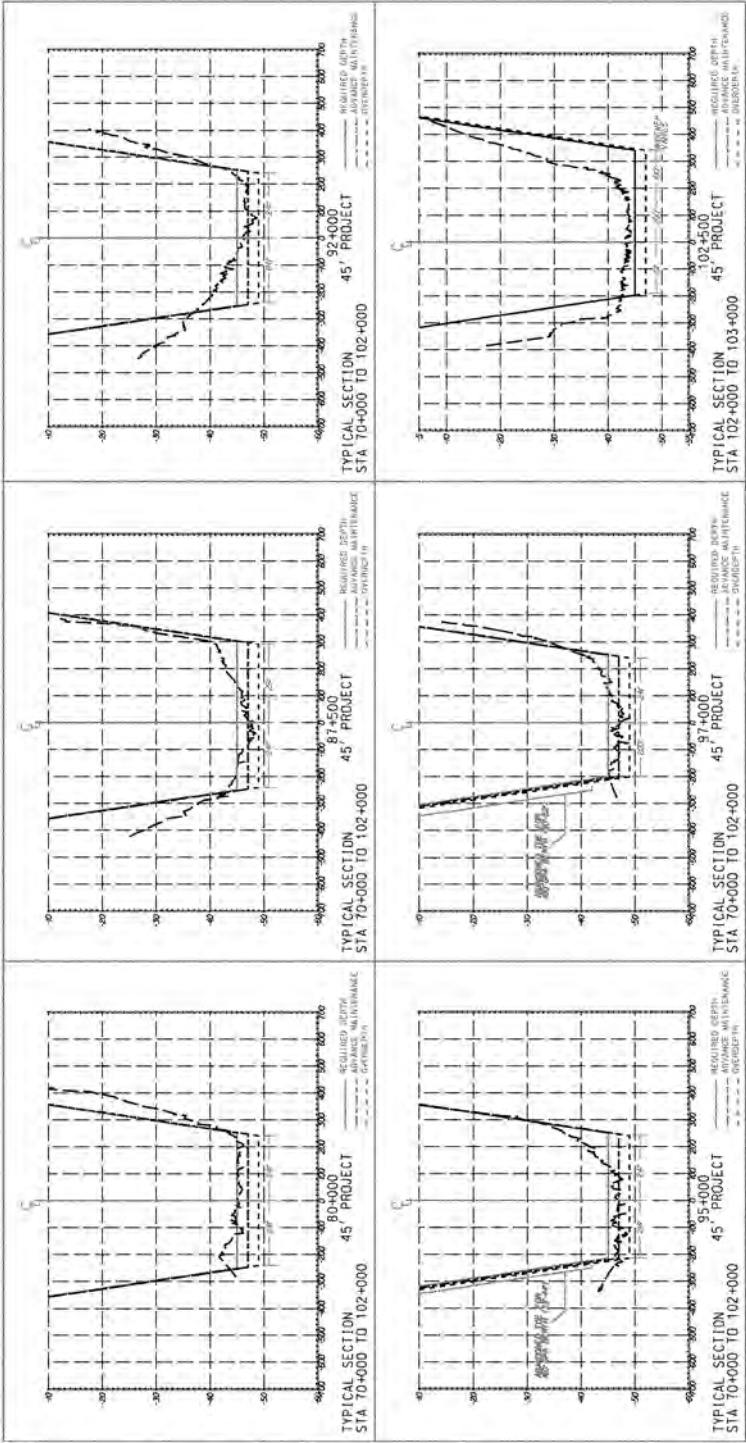


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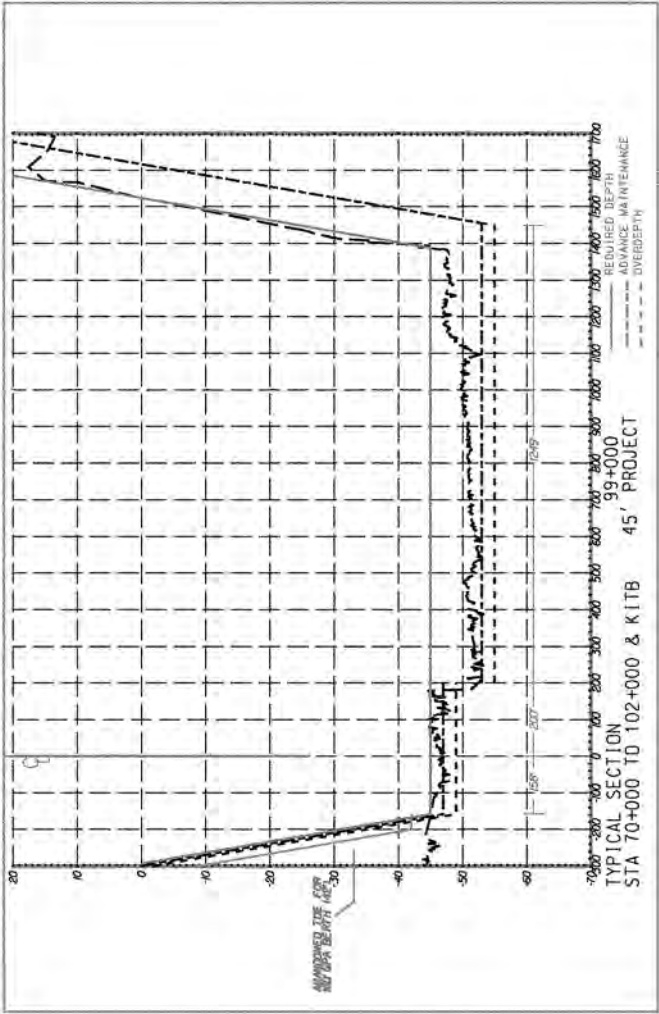


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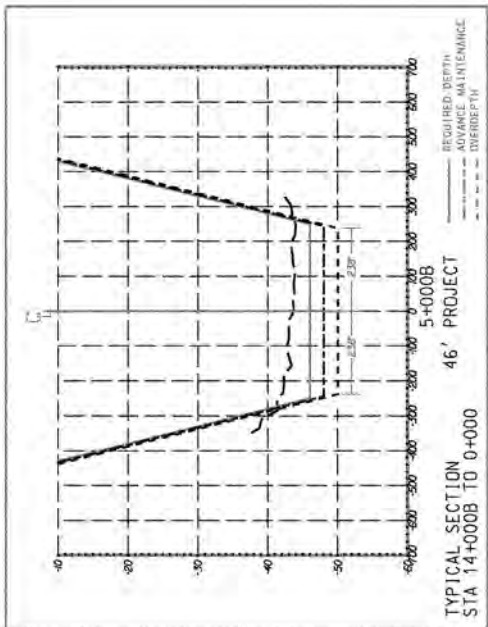




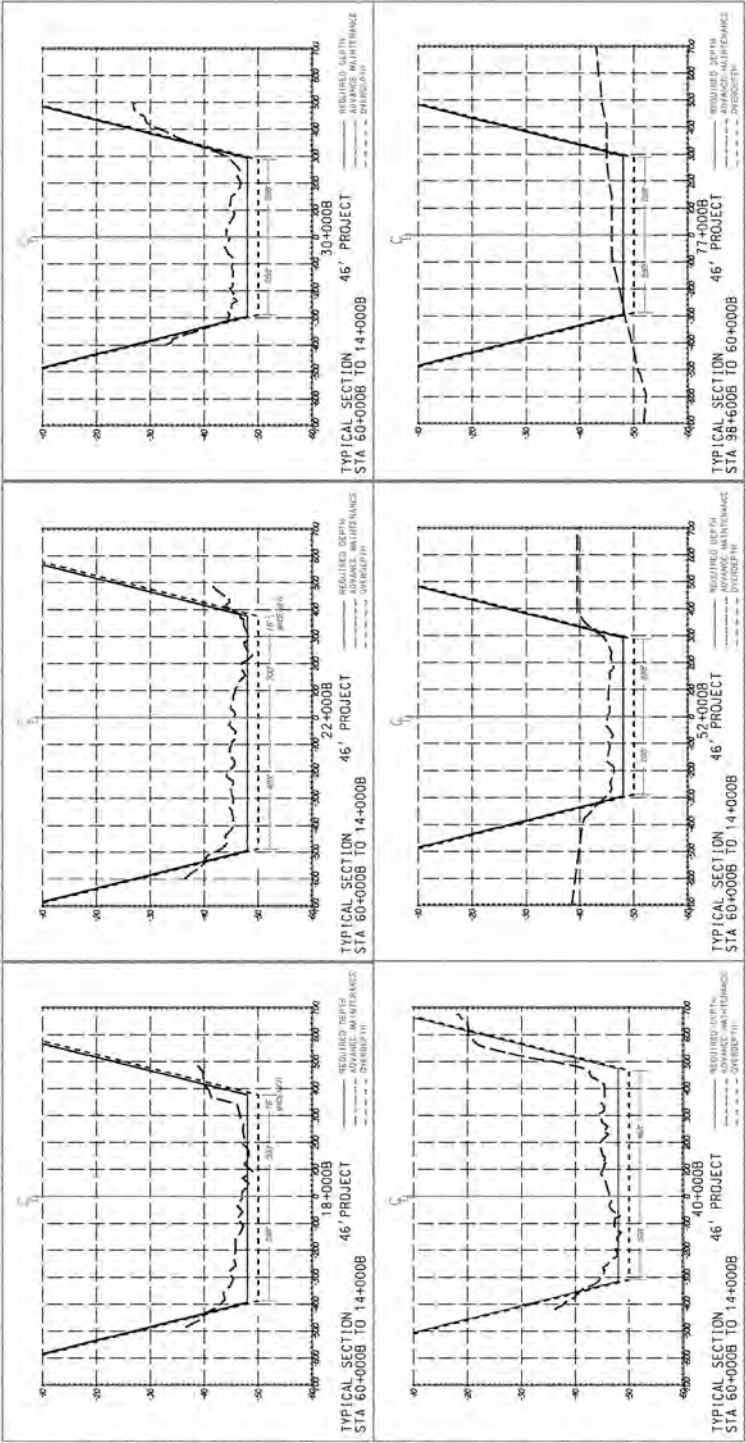
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STATIONS 80+000 TO 102+500



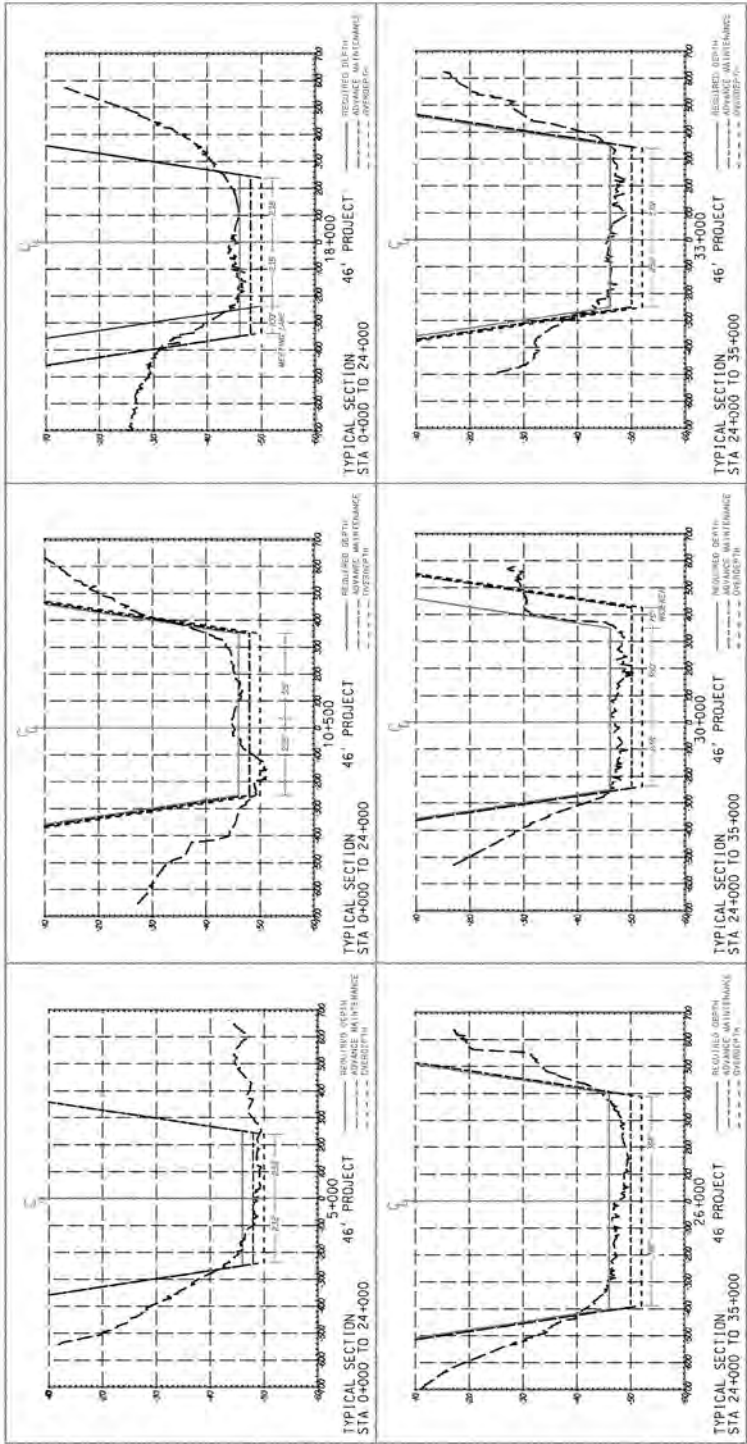
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45' PROJECT  
KINGS ISLAND TURNING BASIN



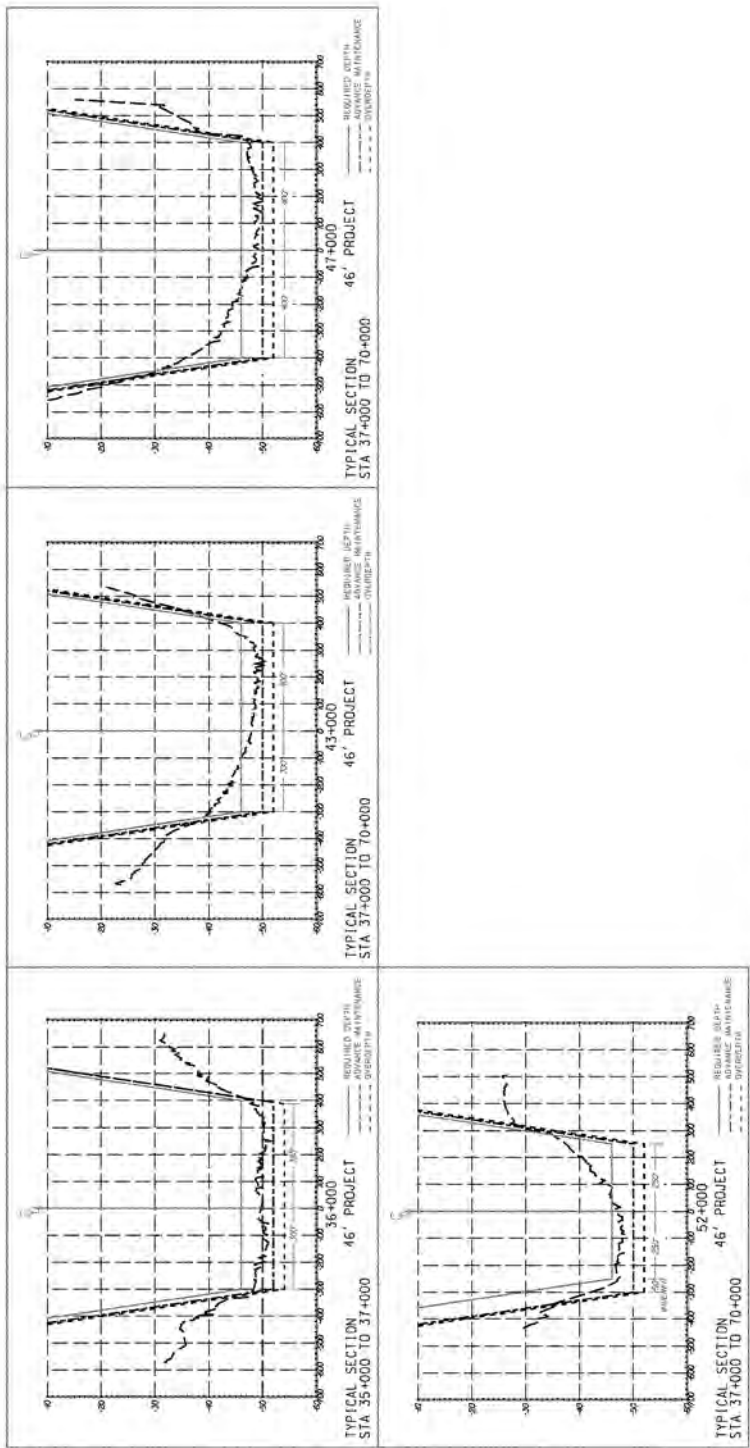
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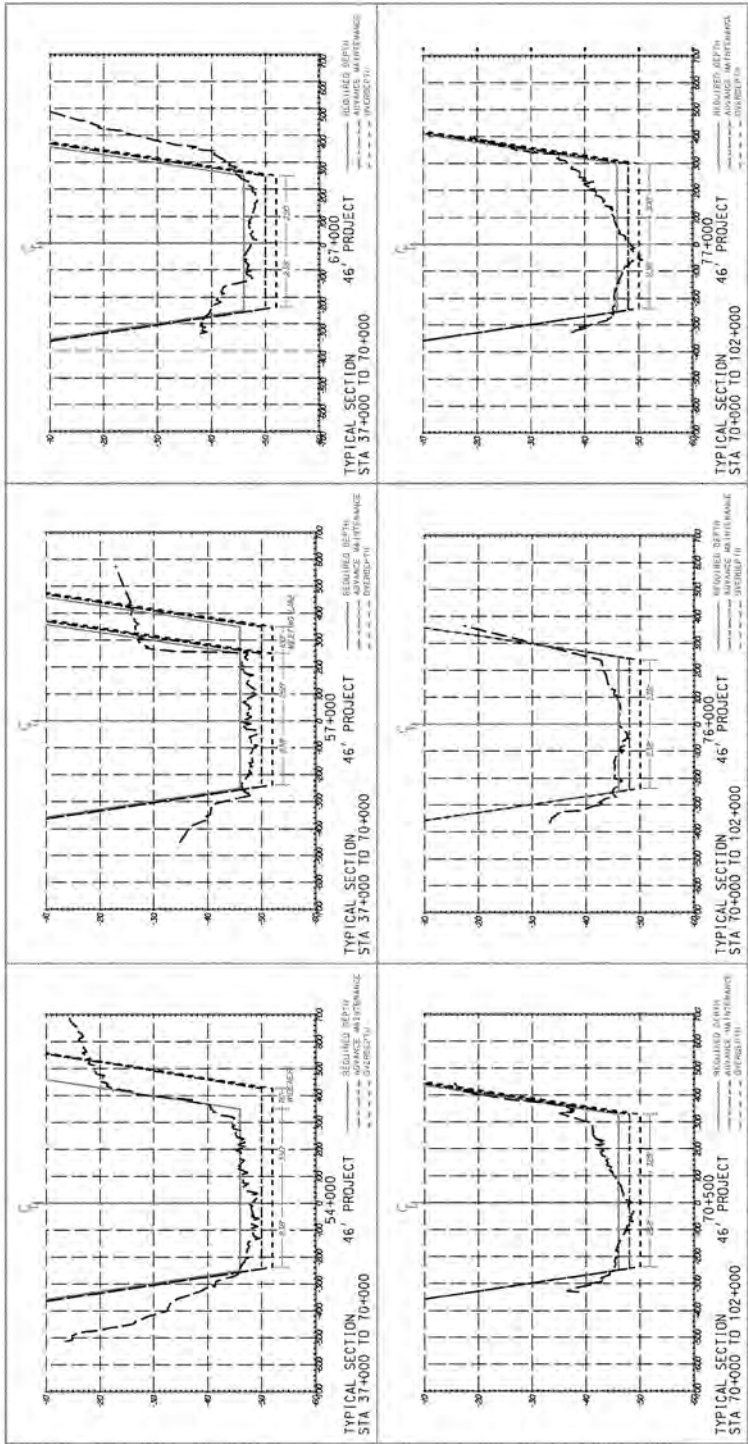
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STATIONS 18+000B TO 77+000B



TYPICAL SECTIONS (LOOKING UPSTREAM)  
46 FOOT PROJECT  
STATIONS 5+000 TO 33+000



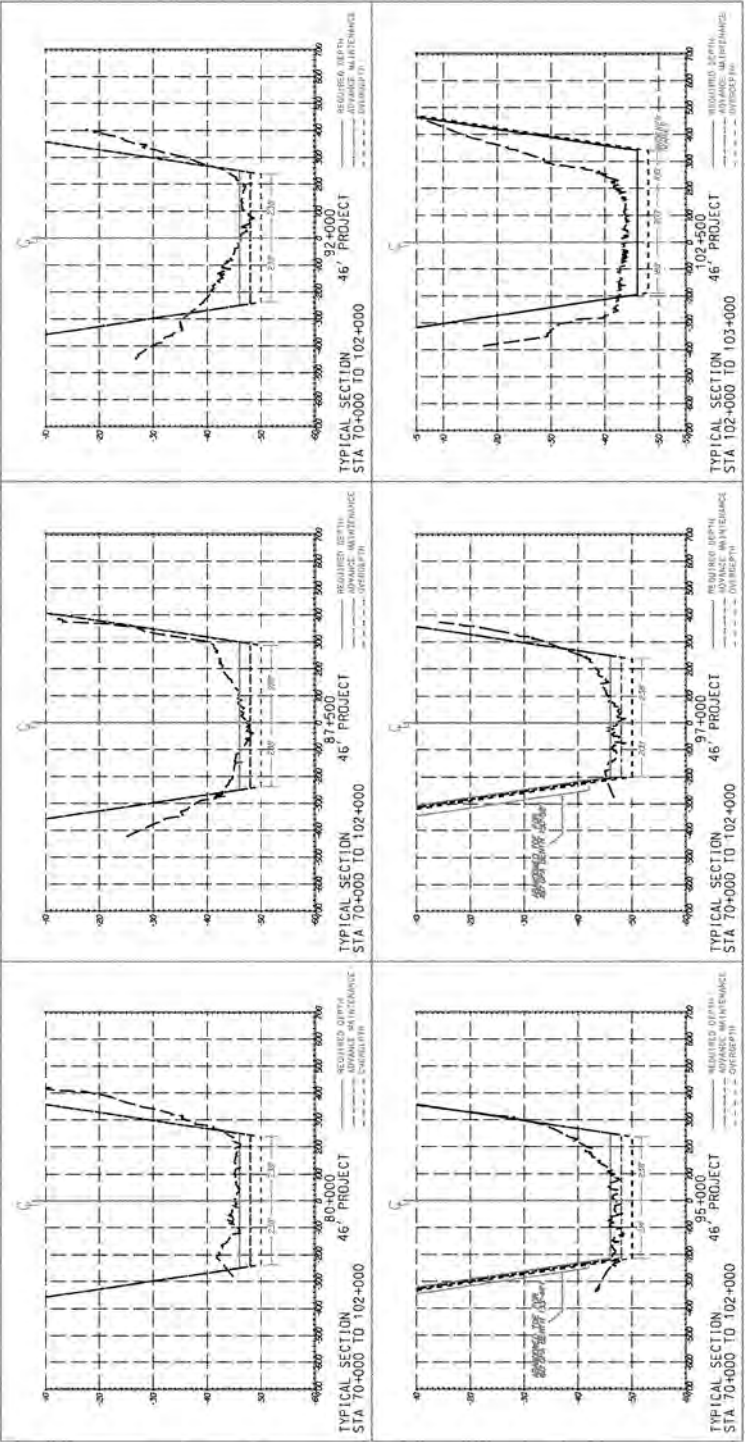
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46 FOOT PROJECT  
STATIONS 36+000 TO 52+000



TYPICAL SECTIONS (LOOKING UPSTREAM)

46 FOOT PROJECT

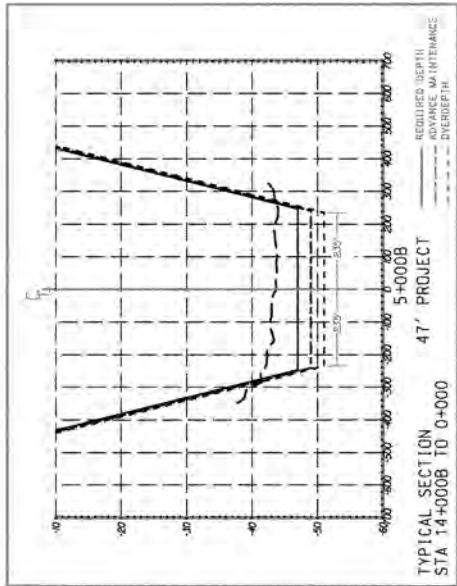
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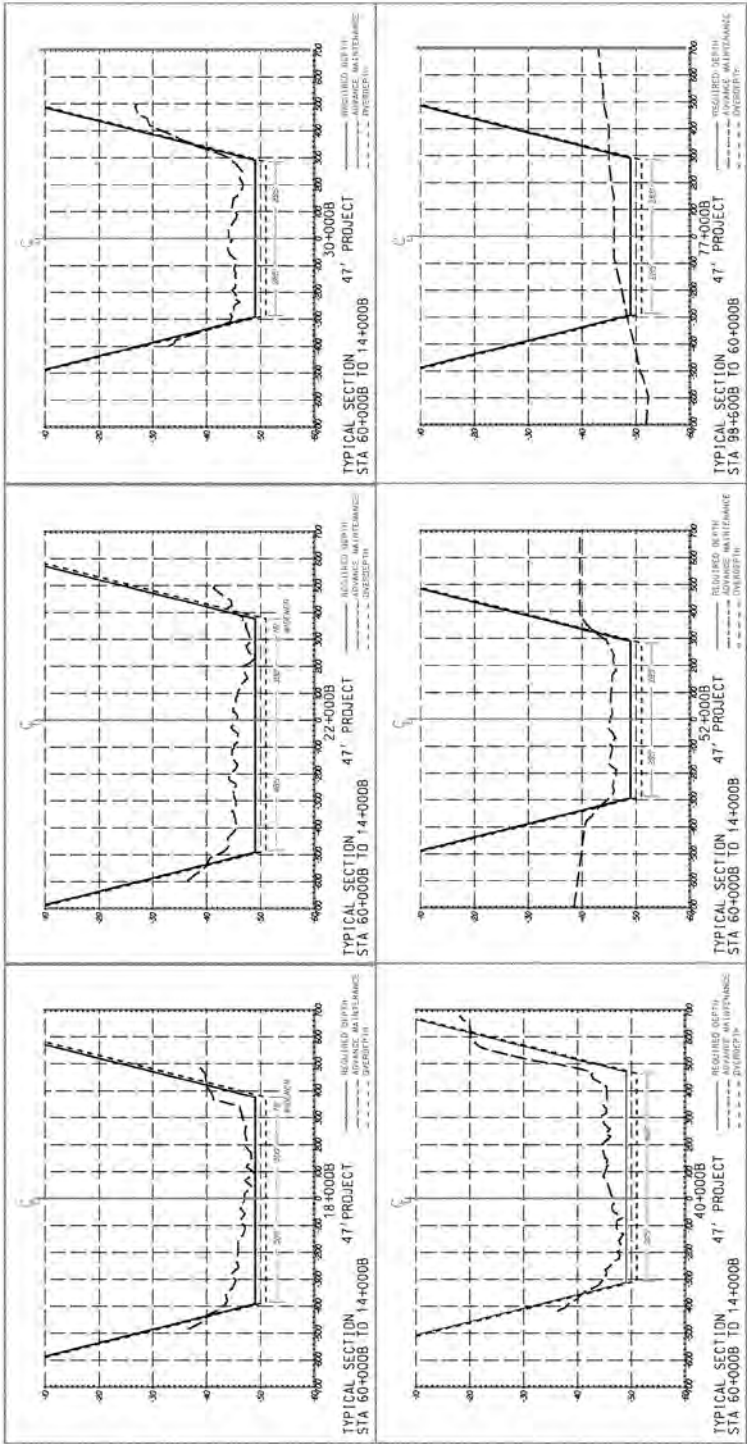
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STATIONS 80+000 TO 102+500



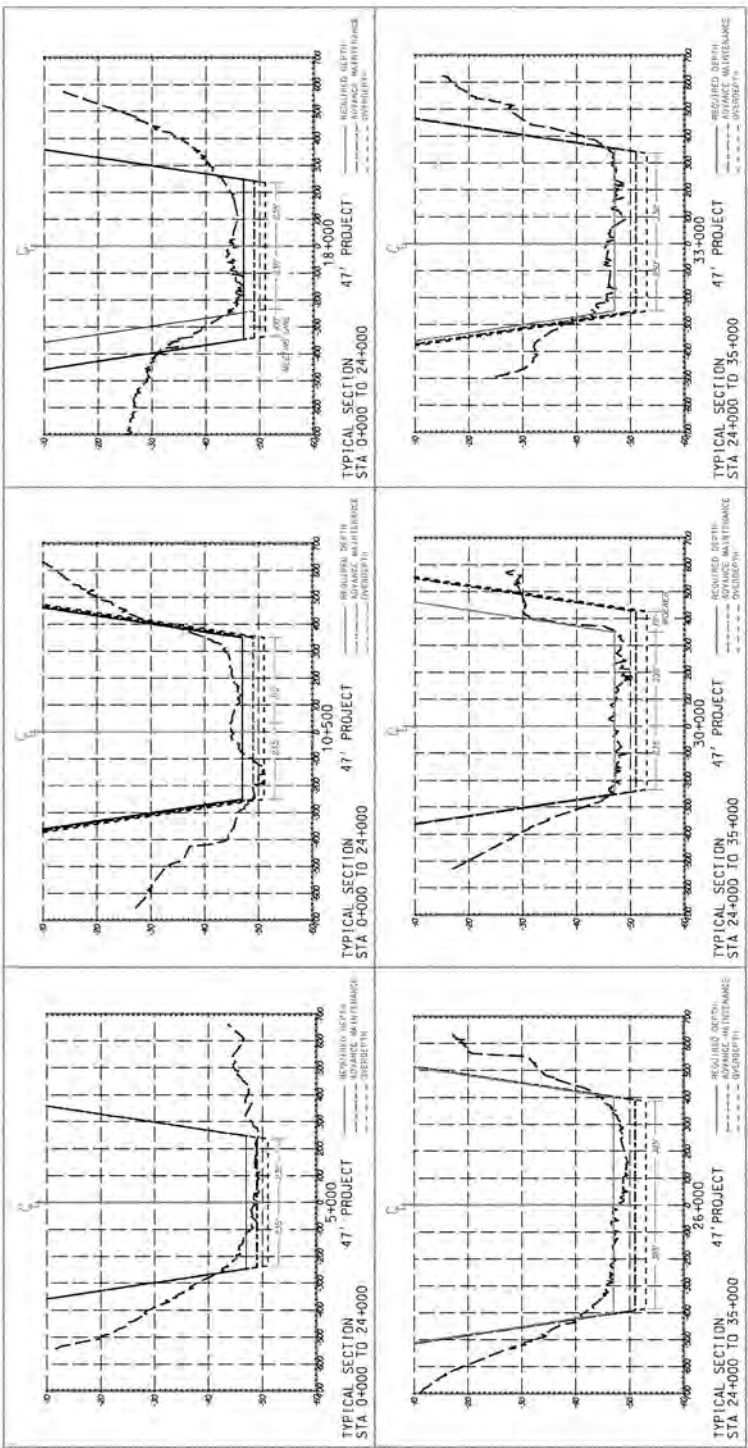




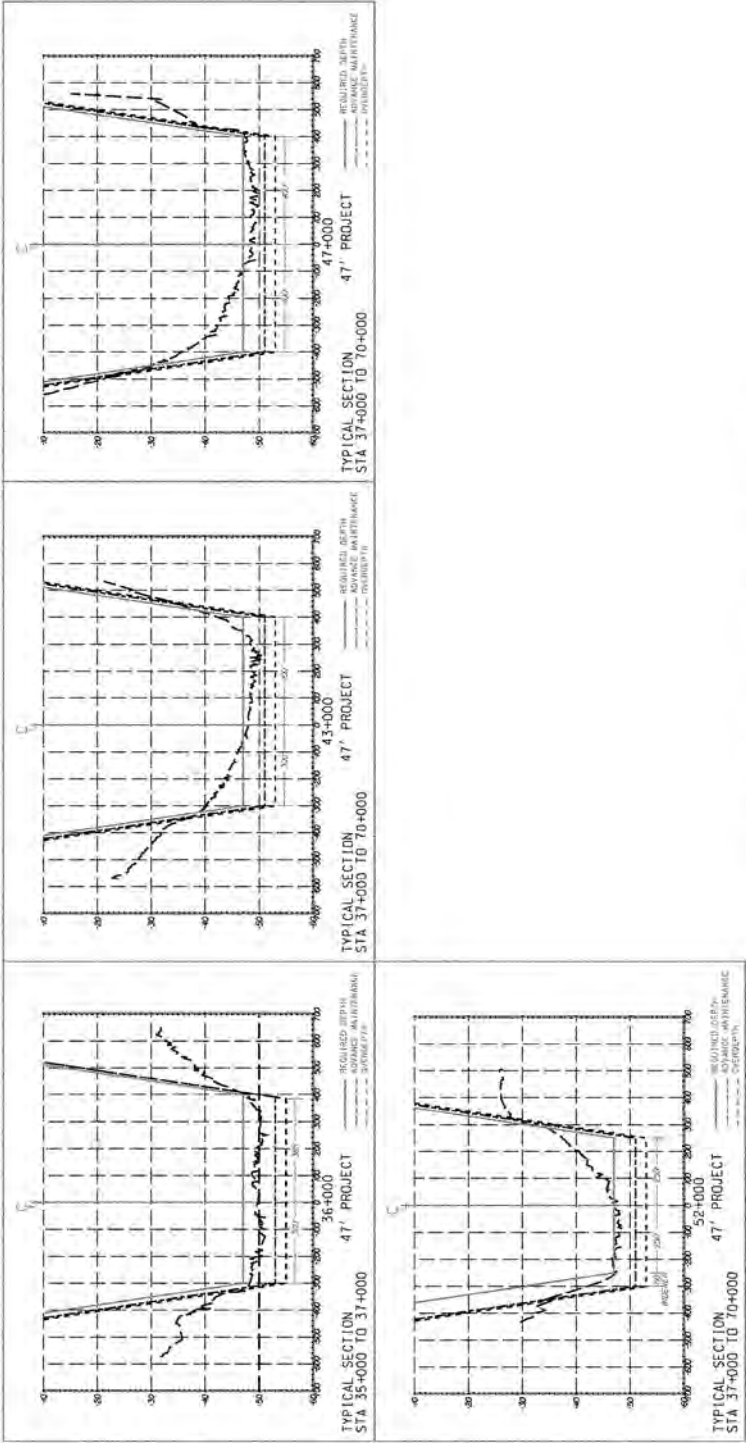
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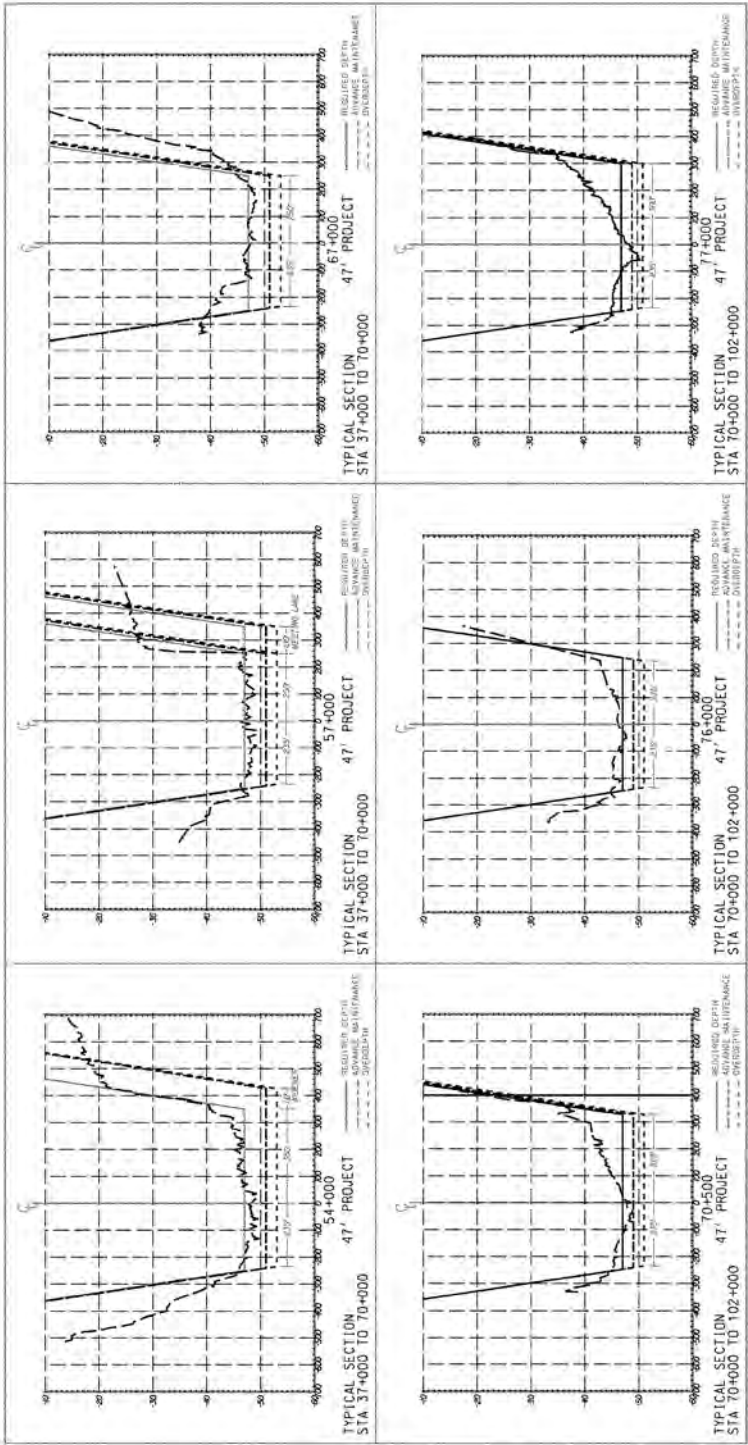
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STATIONS 18+000B TO 77+000B



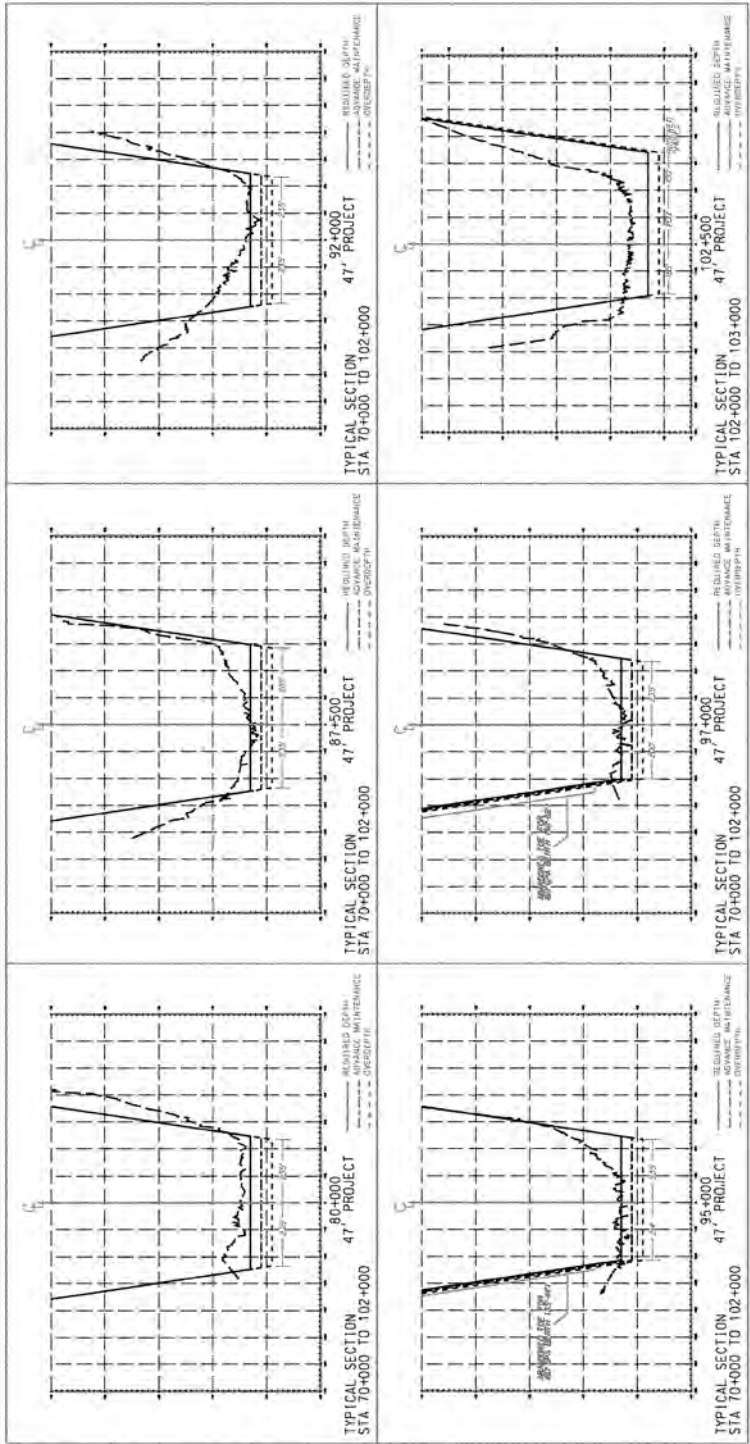
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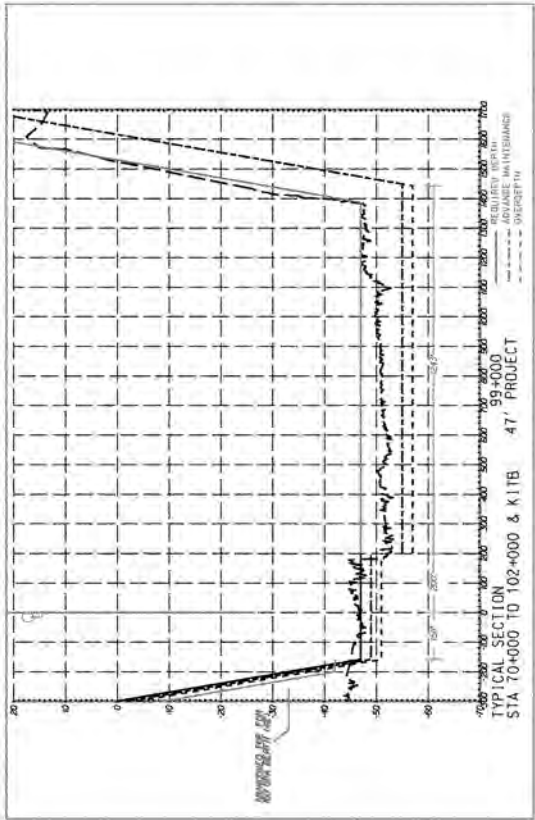
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STATIONS 36+000 TO 52+000



TYPICAL SECTIONS (LOOKING UPSTREAM)  
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STATIONS 54+000 TO 77+000



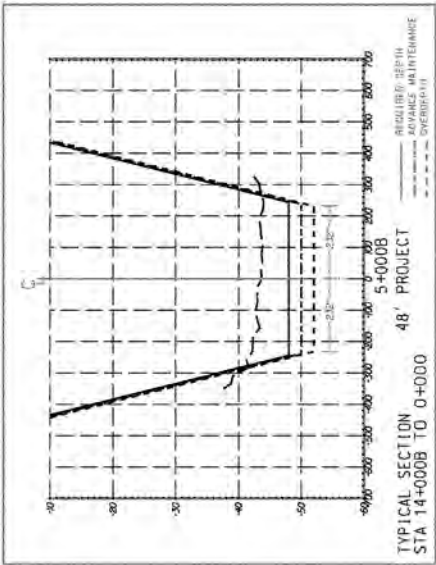
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STATIONS 80+000 TO 102+500

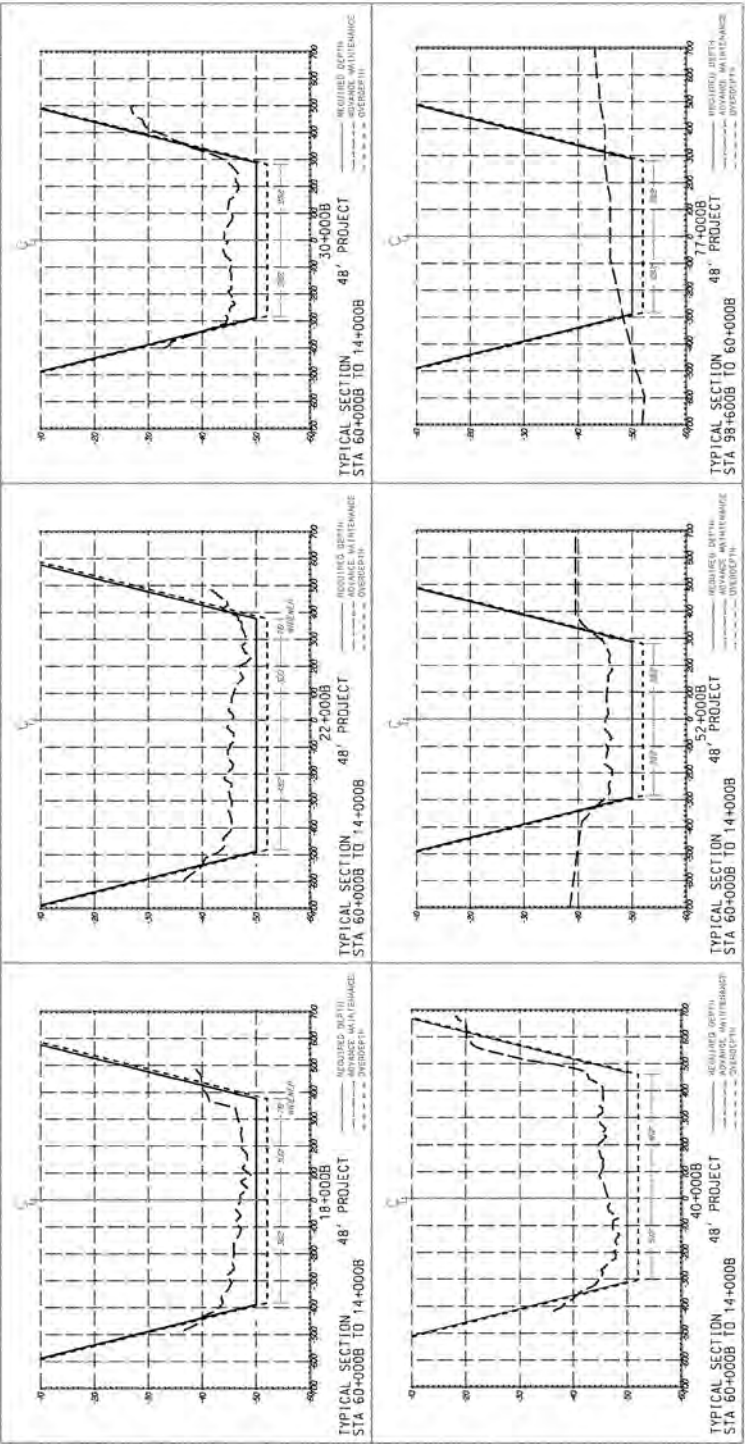


TYPICAL SECTIONS (LOOKING UPSTREAM)  
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KINGS ISLAND TURNING BASIN

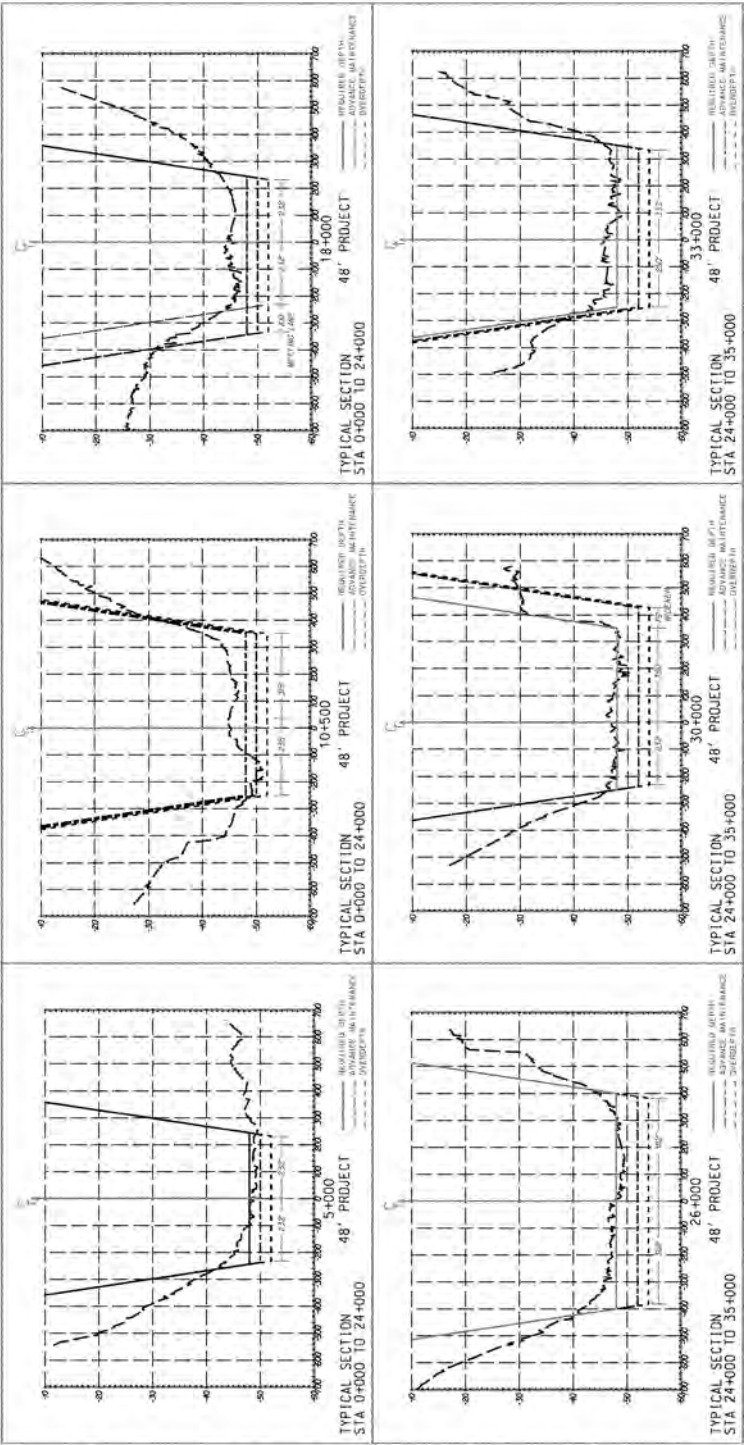


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48 FOOT PROJECT  
STATION 5+000B

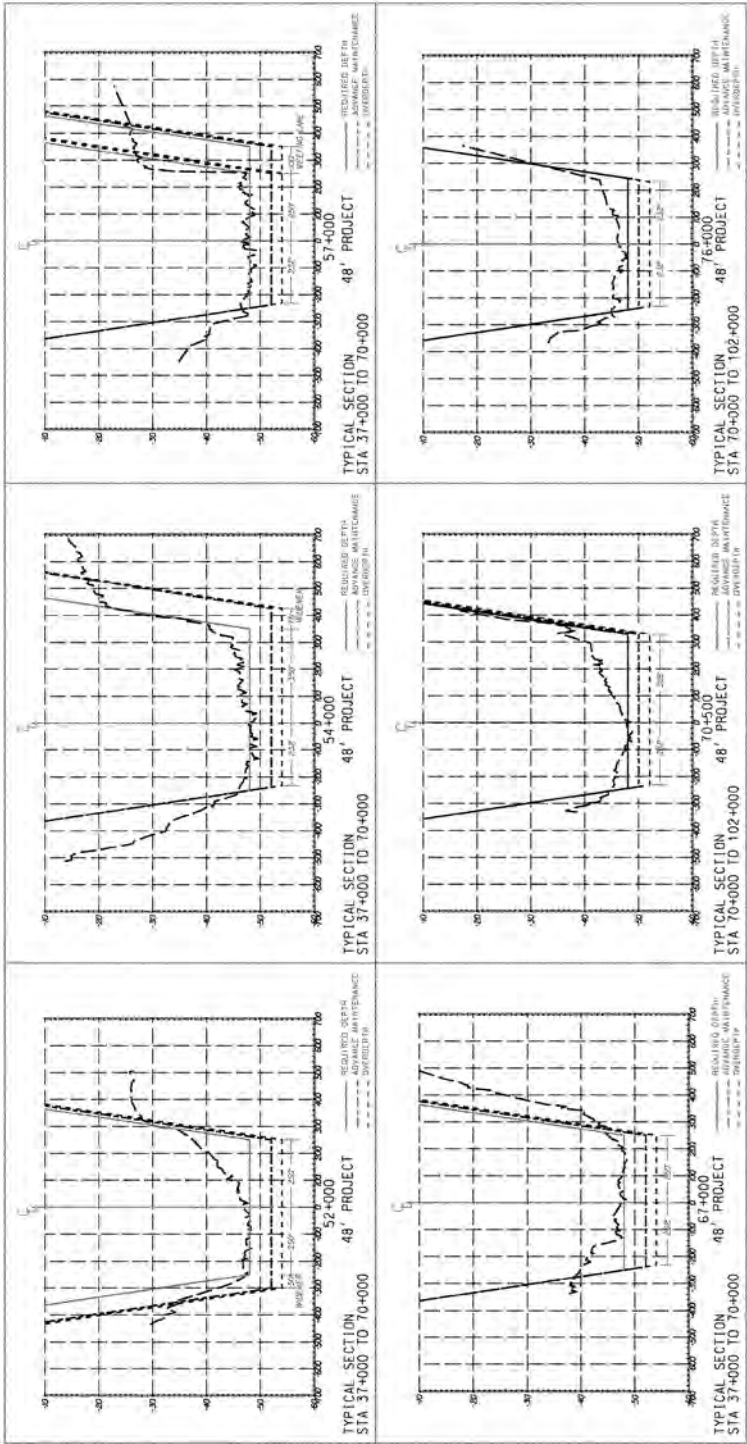




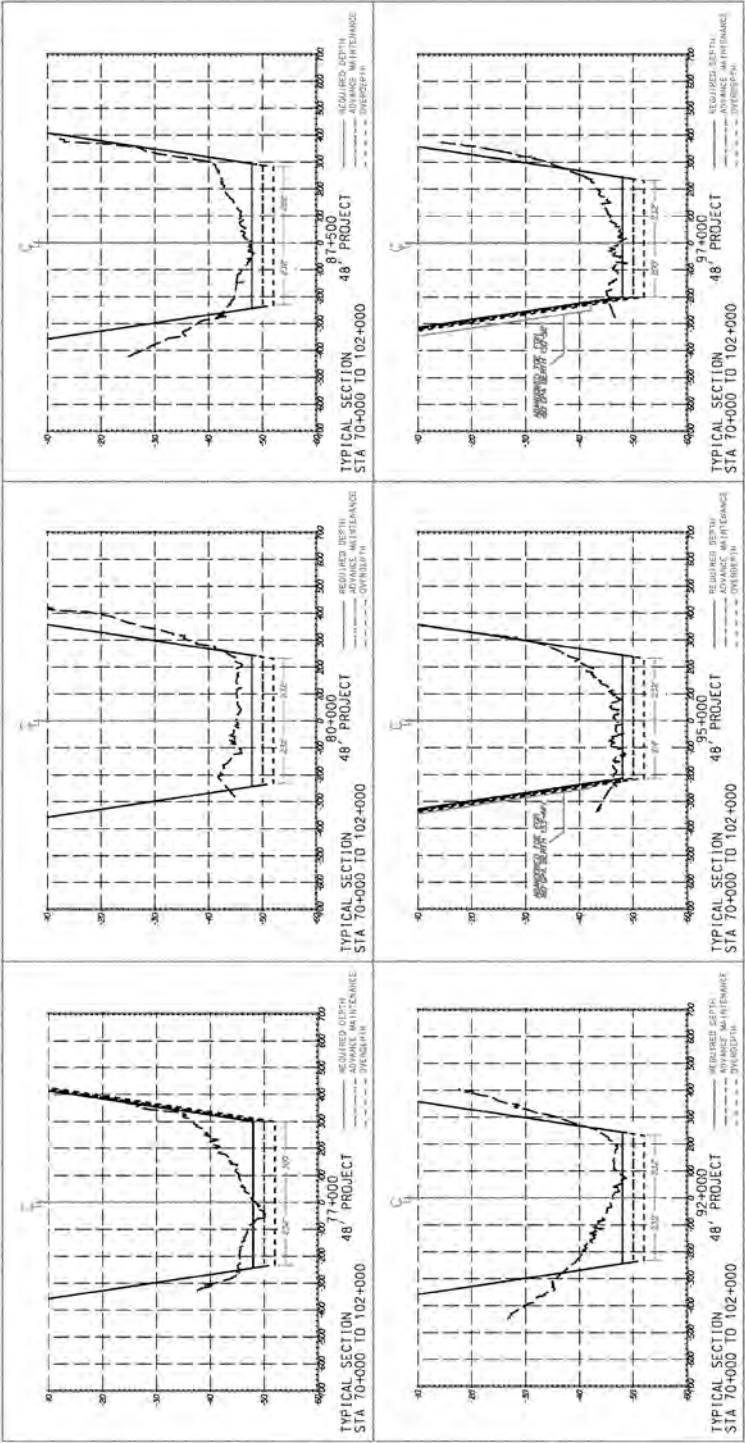
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48 FOOT PROJECT  
STATIONS 18+000B TO 77+000B



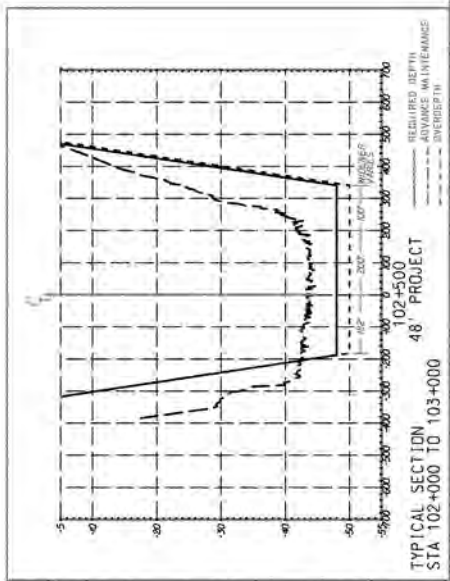
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48 FOOT PROJECT  
STATIONS 5+000 TO 33+000



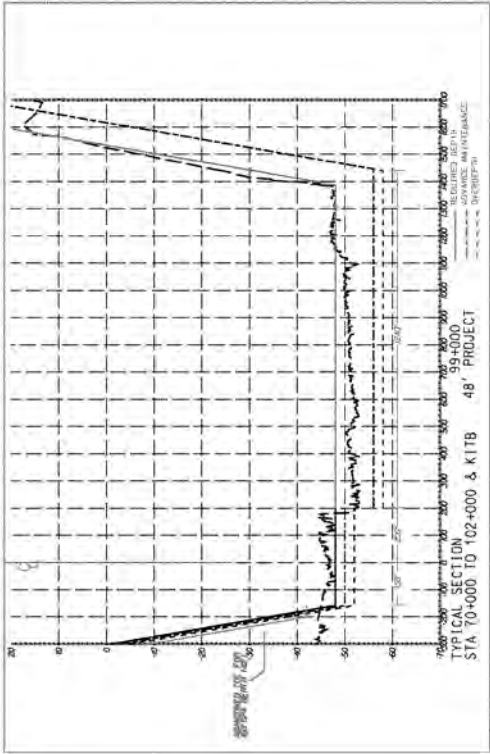
TYPICAL SECTIONS (LOOKING UPSTREAM)  
48 FOOT PROJECT  
STATIONS 52+000 TO 76+000



TYPICAL SECTIONS (LOOKING UPSTREAM)  
48 FOOT PROJECT  
STATIONS 77+000 TO 97+000



TYPICAL SECTION (LOOKING UPSTREAM)  
48 FOOT PROJECT  
STATION 102+500



TYPICAL SECTION (LOOKING UPSTREAM)  
48' PROJECT  
KINGS ISLAND TURNING BASIN

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# **GENERAL RE-EVALUATION REPORT**

## **APPENDIX C: ENGINEERING**

**SAVANNAH HARBOR EXPANSION PROJECT**

Chatham County, Georgia and Jasper County, South Carolina

**January 2012**

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### **ATTACHMENT 2**

**MCACES-MII Cost Estimate and  
Total Project Cost Summary (TCPS)  
Agency Technical Review (ATR)  
Certification**



**US Army Corps  
of Engineers**  
*Savannah District  
South Atlantic Division*



**SAS – SAVANNAH HARBOR EXPANSION PROJECT  
USACE- SAVANNAH DISTRICT**

**COST ENGINEERING DX - TPCS ATR CERTIFICATION UPDATE**

The Savannah Harbor Expansion Project for Savannah District has undergone a successful Cost Agency Technical Review (ATR), performed by the Walla Walla Cost DX ATR representatives. The Cost ATR included an updated study of the project scope, report, cost estimates, schedules, escalation, and risk-based contingencies in accordance with ER 1110-2-1150 Engineering and Design for Civil Works Projects and ER 1110-2-1302 Civil Works Cost Engineering.

As of 5 January 2012, the Walla Walla District, Cost Engineering Directory of Expertise (DX) for Civil Works, certifies the estimated total project cost for the NED Plan 47' depth:

|                      |               |
|----------------------|---------------|
| FY 2013 Price Level: | \$640,899,000 |
| Fully Funded Amount: | \$688,118,000 |

It remains the responsibility of the District to correctly reflect these cost values within the Final Report and to implement effective project controls and implementation procedures.

5 Jan 2012  
Date

  
\_\_\_\_\_  
Kim C. Callan, PE, CCE, PMI  
Chief, Cost Engineering  
Walla Walla District

\*\*\*\* TOTAL PROJECT COST SUMMARY \*\*\*\*

PROJECT: Savannah Harbor Expansion GRR - Tentative NED Plan - 47-FT DESIGN DEPTH  
LOCATION: Savannah, Georgia

DISTRICT: Savannah District  
FOC: CHIEF, COST ENGINEERING, CESAW  
PREPARED: 12/12/2011

This Estimate reflects the scope and schedule in report.  
GENERAL RE-EVALUATION REPORT

| OCTOBER 1, 2010 PRICE LEVEL    |                                                   |           |           |     |           |      |           |           |           |  |
|--------------------------------|---------------------------------------------------|-----------|-----------|-----|-----------|------|-----------|-----------|-----------|--|
| WBS NUMBER                     | Civil Works<br>Evaluate & Sub-Element Description | BASE COST |           |     | CHITG     |      |           | TOTAL     |           |  |
|                                |                                                   | Q         | D         | E   | F         | G    | H         | I         | J         |  |
| A                              |                                                   |           |           |     |           |      |           |           |           |  |
| 06                             | FISH & WILDLIFE FACILITIES                        | \$168,835 | \$42,458  | 25% | \$212,294 | 4.7% | \$177,750 | \$44,439  | \$222,195 |  |
| 12                             | NAVIGATION PORTS & HARBORS                        | \$207,023 | \$51,756  | 25% | \$258,779 | 8.1% | \$223,634 | \$55,069  | \$273,703 |  |
| 18                             | CULTURAL RESOURCE PRESERVATION                    | \$11,132  | \$2,763   | 25% | \$13,895  | 5.7% | \$11,771  | \$2,843   | \$14,713  |  |
| CONSTRUCTION ESTIMATE TOTALS:  |                                                   | \$387,690 | \$96,909  |     | \$484,599 | 5.5% | \$413,351 | \$103,340 | \$516,701 |  |
| 01                             | LANDS AND DAMAGES                                 | \$14,885  | \$3,721   | 25% | \$18,606  | 4.7% | \$16,878  | \$3,895   | \$19,474  |  |
| 30                             | PLANNING, ENGINEERING & DESIGN                    | \$21,400  | \$5,452   | 25% | \$27,258  | 3.0% | \$22,562  | \$5,049   | \$28,241  |  |
| 31                             | CONSTRUCTION MANAGEMENT                           | \$59,057  | \$14,764  | 25% | \$73,821  | 2.0% | \$61,167  | \$15,297  | \$76,484  |  |
| PROJECT COST TOTALS:           |                                                   | \$463,730 | \$120,835 | 25% | \$604,473 | 5.0% | \$512,718 | \$123,160 | \$640,899 |  |
| CHIEF, COST ENGINEERING, CESAW |                                                   |           |           |     |           |      |           |           |           |  |
| PROJECT MANAGER, CESAS         |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, REAL ESTATE, CESAS      |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, PLANNING, CESAS         |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, ENGINEERING, CESAS      |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, OPERATIONS, CESAS       |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, CONSTRUCTION, CESAS     |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, CONTRACTING, CESAS      |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, PM-C, CESAS             |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, DPM, CESAS              |                                                   |           |           |     |           |      |           |           |           |  |

| FULLY FUNDED PROJECT ESTIMATE  |                                                   |           |           |     |           |      |           |           |           |  |
|--------------------------------|---------------------------------------------------|-----------|-----------|-----|-----------|------|-----------|-----------|-----------|--|
| WBS NUMBER                     | Civil Works<br>Evaluate & Sub-Element Description | BASE COST |           |     | CHITG     |      |           | TOTAL     |           |  |
|                                |                                                   | Q         | D         | E   | F         | G    | H         | I         | J         |  |
| A                              |                                                   |           |           |     |           |      |           |           |           |  |
| 06                             | FISH & WILDLIFE FACILITIES                        | \$168,835 | \$42,458  | 25% | \$212,294 | 4.7% | \$177,750 | \$44,439  | \$222,195 |  |
| 12                             | NAVIGATION PORTS & HARBORS                        | \$207,023 | \$51,756  | 25% | \$258,779 | 8.1% | \$223,634 | \$55,069  | \$273,703 |  |
| 18                             | CULTURAL RESOURCE PRESERVATION                    | \$11,132  | \$2,763   | 25% | \$13,895  | 5.7% | \$11,771  | \$2,843   | \$14,713  |  |
| CONSTRUCTION ESTIMATE TOTALS:  |                                                   | \$387,690 | \$96,909  |     | \$484,599 | 5.5% | \$413,351 | \$103,340 | \$516,701 |  |
| 01                             | LANDS AND DAMAGES                                 | \$14,885  | \$3,721   | 25% | \$18,606  | 4.7% | \$16,878  | \$3,895   | \$19,474  |  |
| 30                             | PLANNING, ENGINEERING & DESIGN                    | \$21,400  | \$5,452   | 25% | \$27,258  | 3.0% | \$22,562  | \$5,049   | \$28,241  |  |
| 31                             | CONSTRUCTION MANAGEMENT                           | \$59,057  | \$14,764  | 25% | \$73,821  | 2.0% | \$61,167  | \$15,297  | \$76,484  |  |
| PROJECT COST TOTALS:           |                                                   | \$463,730 | \$120,835 | 25% | \$604,473 | 5.0% | \$512,718 | \$123,160 | \$640,899 |  |
| CHIEF, COST ENGINEERING, CESAW |                                                   |           |           |     |           |      |           |           |           |  |
| PROJECT MANAGER, CESAS         |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, REAL ESTATE, CESAS      |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, PLANNING, CESAS         |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, ENGINEERING, CESAS      |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, OPERATIONS, CESAS       |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, CONSTRUCTION, CESAS     |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, CONTRACTING, CESAS      |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, PM-C, CESAS             |                                                   |           |           |     |           |      |           |           |           |  |
| CHIEF, DPM, CESAS              |                                                   |           |           |     |           |      |           |           |           |  |

|                               |     |           |
|-------------------------------|-----|-----------|
| ESTIMATED FEDERAL COST:       | 70% | \$481,653 |
| ESTIMATED NON-FEDERAL COST:   | 30% | \$206,435 |
| ESTIMATED TOTAL PROJECT COST: |     | \$688,118 |

|                                                         |  |             |
|---------------------------------------------------------|--|-------------|
| ESTIMATED TOTAL PROJECT O&M costs for 50 years          |  | \$3,987,450 |
| Beginning NOV 2016 and includes 25% contingency         |  |             |
| ESTIMATED TOTAL PROJECT O&M costs INCREASE for 50 years |  | \$506,876   |
| Beginning NOV 2016 and includes 25% contingency         |  |             |

\*\*\*\* TOTAL PROJECT COST SUMMARY \*\*\*\*

\*\*\*\* CONTRACT COST SUMMARY \*\*\*\*

|                                                                                                                     |  |  |  |  |  |  |  |  |  |                               |  |
|---------------------------------------------------------------------------------------------------------------------|--|--|--|--|--|--|--|--|--|-------------------------------|--|
| PROJECT: Savannah Harbor Expansion CRR - Tentative NED Plan - 47-FT DESIGN DEPTH                                    |  |  |  |  |  |  |  |  |  | 12/12/2011                    |  |
| LOCATION: Savannah, Georgia                                                                                         |  |  |  |  |  |  |  |  |  | PREPARED:                     |  |
| This Estimate reflects the scope and schedule in report                                                             |  |  |  |  |  |  |  |  |  | Savannah District:            |  |
| GENERAL RE-EVALUATION REPORT                                                                                        |  |  |  |  |  |  |  |  |  | CHIEF, COST ENGINEERING,      |  |
| MAJOR FEATURES - REAL ESTATE, DISSOLVED O2, PRE-MONITORING, CBS GEORGIA, DIKES 14A & 14B, & STRIPED BASS MITIGATION |  |  |  |  |  |  |  |  |  | DISTRICT: SWCH                |  |
| POC:                                                                                                                |  |  |  |  |  |  |  |  |  | POC:                          |  |
| Estimate Prepared: 9-Dec-11                                                                                         |  |  |  |  |  |  |  |  |  | FULLY FUNDED PROJECT ESTIMATE |  |
| Effective Price Level: 1-Qtr-10                                                                                     |  |  |  |  |  |  |  |  |  | 2013                          |  |
| Estimate Price Level                                                                                                |  |  |  |  |  |  |  |  |  | 1 COST Y2                     |  |
| Civil Works                                                                                                         |  |  |  |  |  |  |  |  |  | Program Year (Budget EOL)     |  |
| Excavate & Substructure Disposition                                                                                 |  |  |  |  |  |  |  |  |  | Effective Price Level Date:   |  |
| PHASE 1                                                                                                             |  |  |  |  |  |  |  |  |  | 2013                          |  |
| FISH & WILDLIFE FACILITIES                                                                                          |  |  |  |  |  |  |  |  |  | 2013                          |  |
| - Dissolved O2 system and Water Storage                                                                             |  |  |  |  |  |  |  |  |  | 2013                          |  |
| NAVIGATION PORTS & WAREHOUSES                                                                                       |  |  |  |  |  |  |  |  |  | 2013                          |  |
| - Release Dikes 14A and 14B                                                                                         |  |  |  |  |  |  |  |  |  | 2013                          |  |
| CULTURAL RESOURCE PRESERVATION                                                                                      |  |  |  |  |  |  |  |  |  | 2013                          |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                       |  |  |  |  |  |  |  |  |  | \$105,180                     |  |
| LANDS AND DAMAGES                                                                                                   |  |  |  |  |  |  |  |  |  | \$105,180                     |  |
| PLANNING, ENGINEERING & DESIGN                                                                                      |  |  |  |  |  |  |  |  |  | \$105,180                     |  |
| PED.                                                                                                                |  |  |  |  |  |  |  |  |  | \$105,180                     |  |
| CONSTRUCTION MANAGEMENT                                                                                             |  |  |  |  |  |  |  |  |  | \$105,180                     |  |
| Construction Mgmt, Monitoring, EDC, etc                                                                             |  |  |  |  |  |  |  |  |  | \$105,180                     |  |
| CONTRACT COST TOTALS:                                                                                               |  |  |  |  |  |  |  |  |  | \$105,180                     |  |



\*\*\*\* TOTAL PROJECT COST SUMMARY \*\*\*\*

| PROJECT: Savannah Harbor Expansion (DBB + Turnkey) NED Plan - 47-FT DESIGN DEPTH                                                                         |                                     | DISTRICT: Savannah District    |  | PREPARED: 12/12/2011          |  |
|----------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|--------------------------------|--|-------------------------------|--|
| LOCATION: Savannah, Georgia                                                                                                                              |                                     | POC: CHIEF, COST ENGINEERING   |  |                               |  |
| The Estimate reflects the scope and schedule in report.                                                                                                  |                                     |                                |  |                               |  |
| GENERAL EVALUATION REPORT                                                                                                                                |                                     |                                |  |                               |  |
| MAJOR FEATURES - Dredge, INNER HARBOR, Tidgate & Embankment, Rock Sill Back River, Fill Broad Berm, Fish Passage, Salt Marsh 1-S, Monitor & Dike Raises. |                                     |                                |  |                               |  |
| WBS NUMBERS                                                                                                                                              | Civl Works                          | Estimate Prepared: 8-Dec-11    |  | FULLY FUNDED PROJECT ESTIMATE |  |
|                                                                                                                                                          |                                     | Effective Prior Level: 10x4-10 |  |                               |  |
| A                                                                                                                                                        | Facility & Sub-Facility Description | Program Year (Budget EO): 2013 |  | Mn-Plan                       |  |
|                                                                                                                                                          |                                     | Effective Prior Level: 10x4-10 |  | Date                          |  |
| 06                                                                                                                                                       | PHASE 3                             | EST                            |  | EST                           |  |
|                                                                                                                                                          |                                     | COST                           |  | COST                          |  |
| 12                                                                                                                                                       | FISH & WILDLIFE FACILITIES          | EST                            |  | EST                           |  |
|                                                                                                                                                          |                                     | EST                            |  | EST                           |  |
| 18                                                                                                                                                       | NAVIGATION PORTS & HARBORS          | EST                            |  | EST                           |  |
|                                                                                                                                                          |                                     | EST                            |  | EST                           |  |
| 18                                                                                                                                                       | CULTURAL RESOURCE PRESERVATION      | EST                            |  | EST                           |  |
|                                                                                                                                                          |                                     | EST                            |  | EST                           |  |
| 01                                                                                                                                                       | LANDS AND DAMAGES                   | EST                            |  | EST                           |  |
|                                                                                                                                                          |                                     | EST                            |  | EST                           |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$189,728                      |  | \$189,728                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
| CONSTRUCTION ESTIMATE TOTALS:                                                                                                                            |                                     | \$227,160                      |  | \$227,160                     |  |
| LANDS AND DAMAGES                                                                                                                                        |                                     | \$47,432                       |  | \$47,432                      |  |
| PLANNING, ENGINEERING & DESIGN                                                                                                                           |                                     | \$1,507                        |  | \$1,507                       |  |
| CONSTRUCTION MANAGEMENT                                                                                                                                  |                                     | \$7,564                        |  | \$7,564                       |  |
| CONTRACT COST TOTALS:                                                                                                                                    |                                     | \$203,581                      |  | \$203,581                     |  |
|                                                                                                                                                          |                                     |                                |  |                               |  |

\*\*\* TOTAL PROJECT COST SUMMARY \*\*\*

\*\*\* CONTRACT COST SUMMARY \*\*\*

|                                                                                                           |                                                       |                                                                   |           |                      |                                |
|-----------------------------------------------------------------------------------------------------------|-------------------------------------------------------|-------------------------------------------------------------------|-----------|----------------------|--------------------------------|
| PROJECT: Savannah Harbor Expansion GRR - Tentative NED Plan - 47-FT DESIGN DEPTH                          |                                                       | DISTRICT: Savannah District                                       |           | PREPARED: 12/12/2011 |                                |
| LOCATION: Savannah, Georgia                                                                               |                                                       | POC: CHIEF, COST ENGINEERING                                      |           |                      |                                |
| GENERAL REEVALUATION REPORT                                                                               |                                                       |                                                                   |           |                      |                                |
| The Estimate reflects the scope and schedule in report.                                                   |                                                       |                                                                   |           |                      |                                |
| MAJOR FEATURES - RESTORE DIKE CAPACITY, POST CONSTRUCTION, MONITORING AND ADAPTIVE MGT AFTER CONSTRUCTION |                                                       |                                                                   |           |                      |                                |
| WBS NUMBER                                                                                                | Estimate Prepared: 9 Dec-11<br>Effective Price Level: | Program Year (Budget ECI)<br>Effective Price Level Date: 1 OCT-12 |           |                      | FULLY FUNDED PROJECT ESTIMATE: |
|                                                                                                           |                                                       | ERG<br>J                                                          | COST<br>H | CHTG<br>I            | 2013<br>TOTAL<br>J             |
| A                                                                                                         | Estimate & Sub-Contract (Subcontractor):<br>CHARTER   | ERG<br>G                                                          | COST<br>H | CHTG<br>I            | 2013<br>TOTAL<br>J             |
| 05                                                                                                        | PHASE 4                                               | ERG<br>G                                                          | COST<br>H | CHTG<br>I            | 2013<br>TOTAL<br>J             |
| 12                                                                                                        | FISH & WILDLIFE FACILITIES                            | ERG<br>G                                                          | COST<br>H | CHTG<br>I            | 2013<br>TOTAL<br>J             |
| 12                                                                                                        | NAVIGATION PORTS & HARBORS                            | ERG<br>G                                                          | COST<br>H | CHTG<br>I            | 2013<br>TOTAL<br>J             |
| 18                                                                                                        | -Dike Raises                                          | ERG<br>G                                                          | COST<br>H | CHTG<br>I            | 2013<br>TOTAL<br>J             |
| 18                                                                                                        | CULTURAL RESOURCE PRESERVATION                        | ERG<br>G                                                          | COST<br>H | CHTG<br>I            | 2013<br>TOTAL<br>J             |
| CONSTRUCTION ESTIMATE TOTALS:                                                                             |                                                       | \$7,151                                                           | \$1,700   | \$8,851              | \$9,552                        |
| LANDS AND DAMAGES                                                                                         |                                                       |                                                                   |           |                      |                                |
| 30                                                                                                        | PLANNING, ENGINEERING & DESIGN                        |                                                                   |           |                      |                                |
| 31                                                                                                        | CONSTRUCTION MANAGEMENT                               |                                                                   |           |                      |                                |
| Post Monitoring & Adaptive Mgt.                                                                           |                                                       |                                                                   |           |                      |                                |
| CONTRACT COST TOTALS:                                                                                     |                                                       | \$45,257                                                          | \$11,314  | \$56,571             | \$75,881                       |



- 47 FT DESIGN ALTERNATIVE  
SAVANNAH HARBOR DEEPENING ALTERNATIVES - CURRENT WORKING ESTIMATE (CWE)

Estimated by CESAW-TS-EE  
Designed by USACE - SAVANNAH DISTRICT  
Prepared by John C. Caldwell

Preparation Date: 1/5/2012  
Effective Date of Pricing: 10/1/2010  
Estimated Construction Time: 1,500 Days

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Currency in US dollars

Labor ID: SAV11 EQ ID: EEP09R03

TRACES MII Version 4.1



| Description                                               | Page     |
|-----------------------------------------------------------|----------|
| <b>Project Notes</b>                                      | <b>i</b> |
| <b>Project Cost Summary Report</b>                        | <b>1</b> |
| 01 --LANDS and DAMAGES - REAL ESTATE                      | 1        |
| 06 --FISH and WILDLIFE FACILITIES                         | 1        |
| 12 --NAVIGATION, PORTS, & HARBORS                         | 1        |
| 18 --CULTURAL RESOURCE PRESERVATION                       | 1        |
| 30 --PLANNING, ENGINEERING & DESIGN                       | 1        |
| 31 --SEA-CONST MGT & MITIGATION MONITORING                | 1        |
| <b>Contract Cost Summary Report</b>                       | <b>2</b> |
| 01 --LANDS and DAMAGES - REAL ESTATE                      | 2        |
| 01_01 --Real Estate Analysis Documents                    | 2        |
| 1 Real Estate Analysis Documents                          | 2        |
| 06 --FISH and WILDLIFE FACILITIES                         | 2        |
| 06_03_A --MCCOY CUT DIVERSION CHANNEL - STONE & SHEETPILE | 2        |
| 1 MOB & DEMOB                                             | 2        |
| 2 ARMOR STONE - RIP RAP McCoy Diversion                   | 2        |
| 3 SHEETPILE-FLOW DIVERSION                                | 2        |
| 06_03_B --DEEPPEN MCCOY CUT to -4m                        | 2        |
| 1 MOB & DEMOB                                             | 2        |
| 2 MCCOY'S EXC river, Haul, & Disposal                     | 2        |
| 3 LITTLE BACK RIVER EXC, Haul & Disposal                  | 2        |
| 4 MIDDLE BACK RIVER EXC river, Haul & Disposal            | 2        |
| 06_03_A --ROCK SILL - MOUTH OF BACK RIVER                 | 2        |
| 1 MOB & DEMOB                                             | 2        |
| 2 ARMOR STONE - RIP RAP Back River Rx Sill                | 2        |
| 06_03_D --CLOSE RIFLE CUT - SAND FILL + ARMOR STONE       | 2        |
| 1 MOB & DEMOB                                             | 2        |
| 2 --SAND FILL Rifle Cut                                   | 2        |
| 3 ARMOR STONE - RIP RAP for Rifle Cut                     | 2        |
| 06_03_E --REMOVE TIDEGATE ABUTMENT & PIERS                | 2        |
| 1 MOB-DEMOB                                               | 2        |
| 2 Demolition                                              | 2        |
| 06_03_F --EMBANKMENT REMOVAL at TIDE GATE                 | 2        |
| 1 Mob & Demob                                             | 2        |
| 2 Excavation & beneficial use BY SMALL DREDGE pipeline    | 2        |
| 3 EMBANKMENT EXC & Disposal - UNSUITABLE MATERIAL         | 3        |
| 06_03_G --CLOSE WESTERN LOWER ARM at McCoy's Cut          | 3        |
| 1 MOB & DEMOB                                             | 3        |
| 2 ARMOR STONE - RIP RAP for western McCoy's Cut           | 3        |
| 06_03_H --NEW BOAT RAMP, FLOATING DOCK, and PARKING       | 3        |

| Description                                                     | Page |
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| 1 NEW BOAT RAMP, FLOAT DOCK, PARKG                              | 3    |
| 06_03_1 --NEW SALT MARSH HABITAT at Island "IS"                 | 3    |
| 1 Mob and Demob                                                 | 3    |
| 2 Excavate, GRADE DA-IS                                         | 3    |
| 3 CLEAR & GRUB 42 ACRE MARSH at DA-IS                           | 3    |
| 4 Grade entrance channel BACK at DA-IS                          | 3    |
| 5 Drainage ditch                                                | 3    |
| 6 EXC ENTRANCE CHANNEL TO MARSH AT DA-IS                        | 3    |
| 7 EXC MARSH AREAS - Haul & Disposal by Pumpout into existing DA | 3    |
| 06_03_K --FILL SEDIMENTATION BROAD BERM                         | 3    |
| 1 MOB & DEMOB - PORTABLE DREDGE                                 | 3    |
| 2 FILL using PORTABLE DREDGE                                    | 3    |
| 06_03_L --MITIGATION for Striped Bass                           | 3    |
| 1 Mitigation for Striped Bass - Payments                        | 3    |
| 06_03_M --CONSTRUCT DISSOLVED OXYGEN SYSTEMS                    | 3    |
| 1 Construct Diss Oxygen System                                  | 3    |
| 06_03_N NEW SAVANNAH BLUFF FISH PASSAGE                         | 3    |
| 1 MOB DEMOB                                                     | 3    |
| 2 Armor Stone                                                   | 3    |
| 3 Bedding Stone                                                 | 3    |
| 4 Wier Stone 3.5 x 4.5 ton                                      | 3    |
| 4 Wier Stone 3.5 x 4.5 ton                                      | 4    |
| 5 Clear and Grub                                                | 4    |
| 6 Gate Replacement                                              | 4    |
| 7 Sheetpile                                                     | 4    |
| 8 Excavation                                                    | 4    |
| 9 Access Road                                                   | 4    |
| 06_03_O WATER STORAGE IMPOUNDMENT                               | 4    |
| 1 MOB & DEMOB                                                   | 4    |
| 2 Hardwork                                                      | 4    |
| 3 HDPE Liner                                                    | 4    |
| 4 Sand/Toe Drain Installation                                   | 4    |
| 5 Site Piping, Valves, Accessories                              | 4    |
| 6 Mechanical Mixers                                             | 4    |
| 7 Pump Station - Pumps                                          | 4    |
| 8 Pump Station, Valves and Electrical Building                  | 4    |
| 9 Standby Power, Piping, and Electrical                         | 4    |
| 10 Powered Activated Carbon Silo                                | 4    |
| 11 Misc Stewwork                                                | 4    |
| 12 Testing, Commissioning, Monitoring                           | 4    |
| 12--NAVIGATION, PORTS, & HARBORS                                | 4    |
| 12_02 --Harbors                                                 | 4    |

| Description                                | Page |
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| 1 Moh, Demob & Preparatory Work            | 4    |
| 2 Inner Harb Dredging- 47ft design         | 4    |
| 3 Ocean Bar dredging-47 ft design          | 4    |
| 4 Berthing Area dredging                   | 4    |
| 5 Disposal Area Requirements               | 4    |
| 6 Raise Dikes 14A & 14B -Cadmium           | 4    |
| 7 Debris Removal                           | 5    |
| 8 NAVIGATION AIDS                          | 5    |
| 18 --CULTURAL RESOURCE PRESERVATION        | 5    |
| 18.00 --Cultural Resource Preservation     | 5    |
| 1 Recovery/Removal vessel Georgia          | 5    |
| 2 Preservation on Site                     | 5    |
| 30 --PLANNING, ENGINEERING & DESIGN        | 5    |
| 30.23 --Construction Contracts Documents   | 5    |
| 1 Plans and Specifications (P&S)           | 5    |
| 31 --SEA-CONST MGT & MITIGATION MONITORING | 5    |
| 31.12 --Construction Contracts             | 5    |
| 1 Supervision and Administration           | 5    |
| 31.27 --Mitigation Monitor/Adaptive Mgt    | 5    |
| 1 Preconstruction Monitoring               | 5    |
| 2 Monitoring During Const                  | 5    |
| 3 Post Construction Monitoring             | 5    |
| 4 Adaptive Management                      | 5    |
| 5 Monitor after Adaptive Mgt               | 5    |

| Date       | Author     | Note                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------|------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10/29/2010 | CSA:WNS:EE | <p>This detail estimate is for the 47-FT design depth deepening and mitigation. The Cost Engineering narrative, Section 10 of the Engineering Appendix, was prepared to describe the Current Working Estimate (CWE) alternatives of plan selection for the Savannah Harbor Expansion Project (SHEP) deepening. The alternatives evaluated were to deepen the harbor design depth from an existing 42 ft to a design depth between 44 ft and 48 ft below MLLW. The costs are summarized and listed below in the Code of Accounts format based upon October 2010 price levels. A CWE for construction and non-construction features was developed for each design depth alternative. The existing design depth for the Savannah Harbor is 42 ft below MLLW. Existing advance maintenance depths range from 2 to 8 ft below the design depth at various locations and also include 2-ft of allowable overdepth. A summary of costs with contingencies for all design depths (44 to 48 FT) is shown in TABLE 10-5 of the main GRR and TABLE 13.1-1 of the Engineering Appendix. Evaluations of impacts and benefits determined the National Economic Development (NED) plan to be a 47-FT design depth. The CWE for the 47-FT design depth includes new deepening quantities, 2-foot allowable overdepth quantities, mooring area dredge requirements, required mitigation features including onsite dissolved oxygen injection system, raising existing disposal area dikes, cadmium siltation removal, removal of the Confederate vessel CSS Georgia, Real Estate, Planning, Engineering and Design, Construction Management, and the addition of Navigation Aids. The CWE and Code of Account features for 47-FT design depth are further broken down into more detail in this Microcomputer Aided Cost Estimating System (MCACES) estimate TRACUS MII Version 4.1.4. A Total Project Cost Summary (TPCS), Attachment 2 of the Engineering Appendix, identifies the CWE for the 47-FT design depth for October 2010 as \$483,738,000 (\$604,673,000 with 25% contingency) and fully funded to midpoint of construction as \$688,118,000 with contingency. TPCS estimate certification from the Walla Walla Cost Center DC is included in Attachment-2 of the Engineering Appendix C. The Corps of Engineers Dredge Estimating Program (CHEEP) was used in developing dredging costs throughout the project for medium hopper dredges and large pipeline entrenchment dredges. A Cost Risk and Schedule Analysis (CRSA) was conducted with the Project Delivery Team and the Center of Expertise at Walla Walla District to support a 25% contingency percentage for risk and uncertainty. An updated and final CRSA is incorporated into the final GRR. A final copy of the Cost Risk Report and Risk Register is included in Appendix C-Engineering, Attachment 4.</p> |

| Description                                | Quantity | UOM | ContractCost | Contingency | ProjectCost |
|--------------------------------------------|----------|-----|--------------|-------------|-------------|
| Project Cost Summary Report                |          |     |              |             |             |
| 01 --LANDS and DAMAGES - REAL ESTATE       |          |     | 483,738,075  | 0           | 483,738,075 |
| 06 --FISH and WILDLIFE FACILITIES          | 1        | LS  | 14,884,500   | 0           | 14,884,500  |
| 12 --NAVIGATION, PORTS, & HARBORS          | 1        | LS  | 169,833,877  | 0           | 169,833,877 |
| 18 --CULTURAL RESOURCE PRESERVATION        | 1        | LS  | 207,022,809  | 0           | 207,022,809 |
| 30 --PLANNING, ENGINEERING & DESIGN        | 1        | LS  | 11,131,500   | 0           | 11,131,500  |
| 31 --S&A-CONST MGT & MITIGATION MONITORING | 1        | LS  | 21,806,259   | 0           | 21,806,259  |
|                                            | 1        | LS  | 59,059,130   | 0           | 59,059,130  |

| Description                                              | Quantity | UOM | ContractCost | Contingency | ProjectCost |
|----------------------------------------------------------|----------|-----|--------------|-------------|-------------|
| Contract Cost Summary Report                             |          |     |              |             |             |
| 01 --LANDS and DAMAGES - REAL ESTATE                     |          |     | 483,738,075  | 0           | 483,738,075 |
| 01_01 --Real Estate Analysis Documents                   | 1.00     | LS  | 14,884,500   | 0           | 14,884,500  |
| 1 Real Estate Analysis Documents                         | 1.00     | LS  | 14,884,500   | 0           | 14,884,500  |
| 06 --FISH and WILDLIFE FACILITIES                        |          |     |              |             |             |
| 06_03_A --MCCOY CUT DIVERSION CHANNEL -STONE & SHEETPILE | 1.00     | LS  | 169,833,877  | 0           | 169,833,877 |
| 1 MOB & DEMOB                                            | 1.00     | LS  | 2,324,082    | 0           | 2,324,082   |
| 2 ARMOR STONE - RIP RAP MCCOY Diversion                  | 1.00     | LS  | 211,838      | 0           | 211,838     |
| 3 SHEETPILE-FLOW DIVERSION                               | 1.00     | LS  | 1,448,594    | 0           | 1,448,594   |
| 06_03_B --DEEPEN MCCOY CUT to -4m                        | 1.00     | LS  | 663,650      | 0           | 663,650     |
| 1 MOB & DEMOB                                            | 1.00     | LS  | 7,287,980    | 0           | 7,287,980   |
| 2 MCCOY'S EXC river, Haul, & Disposal                    | 1.00     | LS  | 353,653      | 0           | 353,653     |
| 3 LITTLE BACK RIVER EXC, Haul & Disposal                 | 1.00     | LS  | 1,283,350    | 0           | 1,283,350   |
| 4 MIDDLE BACK RIVER EXC river, Haul & Disposal           | 1.00     | LS  | 4,011,086    | 0           | 4,011,086   |
| 06_03_A --ROCK SILL - - MOUTH OF BACK RIVER              | 1.00     | LS  | 1,639,891    | 0           | 1,639,891   |
| 1 MOB & DEMOB                                            | 1.00     | LS  | 16,824,049   | 0           | 16,824,049  |
| 2 ARMOR STONE - RIP RAP Back River Rx Sill               | 1.00     | LS  | 747,910      | 0           | 747,910     |
| 06_03_D --CLOSE RIFLE CUT - SAND FILL + ARMOR STONE      | 1.00     | LS  | 16,076,139   | 0           | 16,076,139  |
| 1 MOB & DEMOB                                            | 1.00     | LS  | 663,131      | 0           | 663,131     |
| 2 --SAND FILL Rifle Cut                                  | 1.00     | LS  | 57,161       | 0           | 57,161      |
| 3 ARMOR STONE - RIP RAP for Rifle Cut                    | 1.00     | LS  | 105,970      | 0           | 105,970     |
| 06_03_E --REMOVE TIDEGATE ABUTMENT & PIERS               | 1.00     | LS  | 500,001      | 0           | 500,001     |
| 1 MOB-DEMOB                                              | 1.00     | LS  | 2,860,514    | 0           | 2,860,514   |
| 2 Demolition                                             | 1.00     | LS  | 258,167      | 0           | 258,167     |
| 06_03_F --EMBANKMENT REMOVAL at TIDE GATE                | 1.00     | LS  | 2,602,348    | 0           | 2,602,348   |
| 1 Mob & Demob                                            | 1.00     | LS  | 14,375,666   | 0           | 14,375,666  |
|                                                          | 1.00     | LS  | 800,000      | 0           | 800,000     |

| Description                                                     | Quantity | UOM | Contract Cost |  | Contingency |  | Project Cost |  |
|-----------------------------------------------------------------|----------|-----|---------------|--|-------------|--|--------------|--|
|                                                                 |          |     |               |  |             |  |              |  |
| 2 Excavation & beneficial use BY SMALL DREDGE pipeline          | 1.00     | LS  | 4,500,000     |  | 0           |  | 4,500,000    |  |
| 3 EMBANKMENT EXC & Disposal - UNSUITABLE MATERIAL               | 1.00     | LS  | 9,075,666     |  | 0           |  | 9,075,666    |  |
| 06_03_G --CLOSE WESTERN LOWER ARM at McCoy's Cut                | 1.00     | LS  | 1,137,557     |  | 0           |  | 1,137,557    |  |
| 1 MOB & DEMOB                                                   | 1.00     | LS  | 96,927        |  | 0           |  | 96,927       |  |
| 2 ARMOR STONE - RIP RAP for western McCoy's Cut                 | 1.00     | LS  | 1,040,630     |  | 0           |  | 1,040,630    |  |
| 06_03_H --NEW BOAT RAMP, FLOATING DOCK, and PARKING             | 1.00     | LS  | 499,960       |  | 0           |  | 499,960      |  |
| 1 NEW BOAT RAMP, FLOAT DOCK, PARKG                              | 1.00     | LS  | 499,960       |  | 0           |  | 499,960      |  |
| 06_03_I --NEW SALT MARSH HABITAT at Island "IS"                 | 1.00     | LS  | 14,075,959    |  | 0           |  | 14,075,959   |  |
| 1 Mob and Demob                                                 | 1.00     | LS  | 1,500,070     |  | 0           |  | 1,500,070    |  |
| 2 Excavate, GRADE DA-1S                                         | 1.00     | LS  | 2,233,433     |  | 0           |  | 2,233,433    |  |
| 3 CLEAR & GRUB 42 ACRE MARSH at DA-1S                           | 1.00     | LS  | 145,921       |  | 0           |  | 145,921      |  |
| 4 Grade entrance channel BACK at DA-1S                          | 1.00     | LS  | 231,226       |  | 0           |  | 231,226      |  |
| 5 Drainage ditch                                                | 1.00     | LS  | 40,348        |  | 0           |  | 40,348       |  |
| 6 EXC ENTRANCE CHANNEL TO MARSH AT DA-1S                        | 1.00     | LS  | 874,560       |  | 0           |  | 874,560      |  |
| 7 EXC MARSH AREAS , Hauf & Disposal by Pumpout into existing DA | 1.00     | LS  | 9,050,401     |  | 0           |  | 9,050,401    |  |
| 06_03_K --FILL SEDIMENTATION BROAD BERM                         | 1.00     | LS  | 6,690,000     |  | 0           |  | 6,690,000    |  |
| 1 MOB & DEMOB - PORTABLE DREDGE                                 | 1.00     | LS  | 1,800,000     |  | 0           |  | 1,800,000    |  |
| 2 FILL using PORTABLE DREDGE                                    | 1.00     | LS  | 4,890,000     |  | 0           |  | 4,890,000    |  |
| 06_03_L --MITIGATION for Striped Bass - Payments                | 1.00     | LS  | 2,640,000     |  | 0           |  | 2,640,000    |  |
| 1 Mitigation for Striped Bass                                   | 1.00     | LS  | 2,640,000     |  | 0           |  | 2,640,000    |  |
| 06_03_M --CONSTRUCT DISSOLVED OXYGEN SYSTEMS                    | 1.00     | LS  | 56,643,000    |  | 0           |  | 56,643,000   |  |
| 1 Construct Diss Oxygen System                                  | 1.00     | LS  | 56,643,000    |  | 0           |  | 56,643,000   |  |
| 06_03_N NEW SAVANNAH BLUFF FISH PASSAGE                         | 1.00     | LS  | 23,661,978    |  | 0           |  | 23,661,978   |  |
| 1 MOB DEMOB                                                     | 1.00     | LS  | 776,650       |  | 0           |  | 776,650      |  |
| 2 Armor Stone                                                   | 1.00     | LS  | 8,943,864     |  | 0           |  | 8,943,864    |  |
| 3 Bedding Stone                                                 | 1.00     | LS  | 1,705,340     |  | 0           |  | 1,705,340    |  |

| Description                                    | Quantity | UOM | ContractCost | Contingency | ProjectCost |
|------------------------------------------------|----------|-----|--------------|-------------|-------------|
| 4 Wier Stone 3.5 - 4.5 ton                     | 1.00     | LS  | 1,523,072    | 0           | 1,523,072   |
| 5 Clear and Grub                               | 1.00     | LS  | 90,493       | 0           | 90,493      |
| 6 Gate Replacement                             | 1.00     | LS  | 4,000,000    | 0           | 4,000,000   |
| 7 Sheetpile                                    | 1.00     | LS  | 2,367,300    | 0           | 2,367,300   |
| 8 Excavation                                   | 1.00     | LS  | 4,020,830    | 0           | 4,020,830   |
| 9 Access Road                                  | 1.00     | LS  | 234,429      | 0           | 234,429     |
| 06_03_O WATER STORAGE IMPOUNDMENT              | 1.00     | LS  | 20,150,000   | 0           | 20,150,000  |
| 1 MOB and DEMOB                                | 1.00     | LS  | 51,961       | 0           | 51,961      |
| 2 Earthwork                                    | 1.00     | LS  | 5,493,400    | 0           | 5,493,400   |
| 3 HDPE Liner                                   | 1.00     | LS  | 1,015,000    | 0           | 1,015,000   |
| 4 Sand/Tue Drain Installation                  | 1.00     | LS  | 1,079,370    | 0           | 1,079,370   |
| 5 Site Piping, Valves, Accessories             | 1.00     | LS  | 3,255,132    | 0           | 3,255,132   |
| 6 Mechanical Mixers                            | 1.00     | LS  | 94,311       | 0           | 94,311      |
| 7 Pump Station - Pumps                         | 1.00     | LS  | 2,666,400    | 0           | 2,666,400   |
| 8 Pump Station, Valves and Electrical Building | 1.00     | LS  | 990,731      | 0           | 990,731     |
| 9 Standby Power, Piping, and Electrical        | 1.00     | LS  | 2,289,829    | 0           | 2,289,829   |
| 10 Powered Activated Carbon Sift               | 1.00     | LS  | 1,062,089    | 0           | 1,062,089   |
| 11 Misc Sitework                               | 1.00     | LS  | 1,842,346    | 0           | 1,842,346   |
| 12 Testing, Commissioning, Monitoring          | 1.00     | LS  | 309,431      | 0           | 309,431     |
| 12 --NAVIGATION, PORTS, & HARBORS              | 1.00     | LS  | 207,022,809  | 0           | 207,022,809 |
| 12_02 --Harbors                                | 1.00     | LS  | 207,022,809  | 0           | 207,022,809 |
| 1 Mob, Demob & Preparatory Work                | 1.00     | LS  | 23,700,000   | 0           | 23,700,000  |
| 2 Inner Harb Dredging- 47ft design             | 1.00     | LS  | 101,673,609  | 0           | 101,673,609 |
| 3 Ocean Bar dredging-47 ft design              | 1.00     | LS  | 57,760,483   | 0           | 57,760,483  |
| 4 Berthing Area dredging                       | 1.00     | LS  | 2,066,851    | 0           | 2,066,851   |
| 5 Disposal Area Requirements                   | 1.00     | LS  | 6,613,866    | 0           | 6,613,866   |



| Description                                | Quantity | UOM | ContractCost | Contingency | ProjectCost |
|--------------------------------------------|----------|-----|--------------|-------------|-------------|
| 6 Raise Dikes 14A & 14B-Cadmium            | 1.00     | LS  | 9,500,000    | 0           | 9,500,000   |
| 7 Debris Removal                           | 1.00     | LS  | 1,688,000    | 0           | 1,688,000   |
| 8 NAVIGATION AIDS                          | 1.00     | LS  | 4,020,000    | 0           | 4,020,000   |
| 18 -CULTURAL RESOURCE PRESERVATION         | 1.00     | LS  | 11,131,500   | 0           | 11,131,500  |
| 18_00 --Cultural Resource Preservation     | 1.00     | LS  | 11,131,500   | 0           | 11,131,500  |
| 1 Recovery/Removal vessel Georgia          | 1.00     | LS  | 9,500,000    | 0           | 9,500,000   |
| 2 Preservation on Site                     | 1.00     | LS  | 1,631,500    | 0           | 1,631,500   |
| 30 -PLANNING, ENGINEERING & DESIGN         | 1.00     | LS  | 21,806,259   | 0           | 21,806,259  |
| 30_23 --Construction Contracts Documents   | 1.00     | LS  | 21,806,259   | 0           | 21,806,259  |
| 1 Plans and Specifications (P&S)           | 1.00     | LS  | 21,806,259   | 0           | 21,806,259  |
| 31 --S&A-CONST MGT & MITIGATION MONITORING | 1.00     | LS  | 59,059,130   | 0           | 59,059,130  |
| 31_12 --Construction Contracts             | 1.00     | LS  | 10,903,130   | 0           | 10,903,130  |
| 1 Supervision and Administration           | 1.00     | LS  | 10,903,130   | 0           | 10,903,130  |
| 31_27 --Mitigation Monitor/Adaptive Mgt    | 1.00     | LS  | 48,156,000   | 0           | 48,156,000  |
| 1 Preconstruction Monitoring               | 1.00     | LS  | 2,893,000    | 0           | 2,893,000   |
| 2 Monitoring During Const                  | 1.00     | LS  | 8,734,000    | 0           | 8,734,000   |
| 3 Post Construction Monitoring             | 1.00     | LS  | 16,828,000   | 0           | 16,828,000  |
| 4 Adaptive Management                      | 1.00     | LS  | 16,701,000   | 0           | 16,701,000  |
| 5 Monitor after Adaptive Mgt               | 1.00     | LS  | 3,000,000    | 0           | 3,000,000   |

**Revised 35% Design Construction Cost Estimate**

**New Savannah Bluff Dam Fish Passage Facility  
Richmond County, Georgia**

**December 3, 2002**

**Submitted To:**

**Mobile District, USACE  
109 St. Joseph Street  
Mobile, Alabama 36602**

**Submitted By:**



**BTG Inc. Delta Engineering Technology Division  
1501 Merchants Way  
Niceville, Florida 32578  
(850) 897-5380**



Todd Koski  
Cost Estimator

December 3, 2002

Mobile District, USACE  
Attn: Mr. Bill Griffin;  
109 St. Joseph Street  
Mobile, Alabama 36602

SUBJECT: New Savannah Bluff Dam Fish Passage Facility,  
Richmond County, Georgia

Dear Mr. Griffin:

We are pleased to submit the attached Phase II Feasibility Study (35% design) estimate for the New Savannah Bluff Dam Fish Passage Facility project.

1. The enclosed estimate reflects our best cost evaluation for the current construction bidding climate. Our estimate is based on the assumption of open competitive bidding by the parties involved. This estimate does not include furnishings, professional fees, equipment, abatement of hazardous materials, municipal impact fees, utility tap fees, or any items not specifically identified in the itemized report.
2. Existing conditions and dimensional information were derived from the drawings, specifications, design analysis, and other technical information dated November 2002.
3. This estimate is based on a mid-point of construction of July 2004. Prices will increase at a rate tied to inflation if this date changes. This estimate also assumes a project duration of eight months. Contractor expenses may change if the project duration is changed.
4. This estimate is based on the information available at this time. The final costs of the project will depend on the actual labor and material costs, competitive market conditions, final project scope, implementation schedule, and other variable factors at the time of award. As a result, the final project costs most likely will vary from the estimate. Because of this, project feasibility and funding availability should be carefully reviewed prior to making specific financial decisions, to help ensure proper project evaluation, choices, and adequate funding.
5. The estimate is based on the assumption that all access will be across the lake from the Georgia Park site.
6. Per our discussions with Mr. Ron Grady at Framatome ANP, we have allowed fifteen working days to make the final stone adjustments in the channel.

7. Estimated quantities are based on the Material Quantity Estimate supplied by Framatome. These quantities have been validated with our own quantity take-off calculations. The estimate reflects minor modifications to the provided Material Quantities Estimate as noted on the attached copy of the quantities shown in the backup documentation.

BTG appreciates the opportunity to provide this estimating service. If you have any questions about this estimate, please give me a call at (850) 897-5380.

Sincerely,

Todd Koski  
Cost Estimator

# **COST ESTIMATE SUBMITTAL** **CHECKLIST**

**COST ESTIMATE SUBMITTAL CHECKLIST**

**Project:** Savannah Bluff Dam Fish Passage Facility  
**Location:** Savannah Bluff Dam, Richmond County, Georgia  
**A-E Name:** Framatome ANP DE&S, Inc.

## **[X] Construction Cost Estimate**

**Check Type of Estimate Program:**    ☐ Military  
                                                          ☒ Civil  
                                                          ☐ HTRW  
                                                          ☐ Other (specify) \_\_\_\_\_

**Check Level of Estimate: Military:**   ☐ Programming Effort  
                                                          ☐ Project Definition  
                                                                  ☐ Initial            ☐ Final  
                                                          ☐ Concept  
                                                          ☐ Interim  
                                                          ☐ Final  
                                                          ☐ Ready-To-Advertise  
                                                          ☐ Change Order  
                                                          ☐ Other (specify) \_\_\_\_\_

**Civil:**    ☐ Reconnaissance  
                  ☐ DM/Baseline  
                  ☐ Plans and Specs  
                  ☒ Other (35% Design)

**HTRW:**    ☐ Level of Design \_\_\_\_\_

**Other:**    ☐ Level of Design \_\_\_\_\_

**Type of Cost Estimate:**                ☐ Manual (pencil)  
                                                          ☐ PACES  
                                                          ☒ MCACES GOLD  
                                                          ☐ Excel Spreadsheet  
                                                          ☐ Other (specify) \_\_\_\_\_

**Estimate Hierarchy:**                    ☒ Normal Work Breakdown Structure (WBS)  
                                                          ☐ Full Work Breakdown Structure (WBS)  
                                                          ☐ Partial Work Breakdown Structure (WBS)  
                                                          ☐ Special (Separate Handout)

**Note:** The RTA cost estimate that is submitted to the Government shall be accompanied by a letter of transmittal which includes the following statement: "To

the best of my knowledge the confidential nature of this estimate has been maintained”

**[ ] AF Form 1178 (AF Projects Only)**

**[X] 1.44MB 3-1/2” Diskettes containing a electronic copy of the PROJECT DATABASE, and a separate Diskette of the Labor Rates Database. These databases shall be “SAVE TO COMPRESSED” DO NOT CHANGE ANY OTHER DATABASES.**

**[X] Supporting Data:**

**[X] Quantity Survey Documentation**

**[X] Quantity Derivations**

**[X] Current Price Quotations**

**[X] HAG Data Sheet**

**[N/A] Annotated Comments, as appropriate**

# **HAG DATA SHEET**



## **HAG DATA INPUT SHEET**

(Estimate Must Be Prepared Using the Work Breakdown Structure to the Fourth Level)

**PROJECT NAME:** Savannah Bluff Dam Fish Passage Facility

**PROJECT LOCATION:** Savannah Bluff Dam, Richmond County, Georgia

**PROJECT NUMBER:** \_\_\_\_\_ (Not Required from A-E)  
(Use last 9 digits of Solicitation Number, including Hyphens)

**SERVICE:** (circle one) 1. Army 2. Air Force 3. Navy 4. Civil 5. Other

**PROGRAM YEAR:** FY 02

**POC:** \_\_\_\_\_ (Not Required from A-E)

**PREPARED BY:** (circle one) 1. A-E 2. In-House

**ESTIMATE TYPE:** \_\_\_\_\_ (Not Required from A-E)

**PROJECT DESCRIPTION:**

The scope of this project consists of construction of a new fish passage facility (fish ladder) using the "horseshoe" configuration based on the Phase II Feasibility documents dated November 2002.

**A-E or COST CONSULTANT (Company Name):** BTG Inc. Applied Engineering Solutions

**PROGRAMMED AMOUNT:** \_\_\_\_\_ (Not Required from A-E)

**CATEGORY CODE:** \_\_\_\_\_ (Not Required from A-E)

Savannah Bluff Fish Bypass Sys  
Savannah Bluff Lock & Dam  
Richmond County, GA  
Phase II Feasibility Study  
13A Design

Designed BY: Pamarcose AMP D&S  
Estimated BY: JRM & TK

Prepared BY: Titan Systems Corporation  
Applied Engineering Solutions

Preparation Date: 12/03/02  
Effective Date of Project: 12/03/02  
Est Construction Time: 240 Days  
Sales Tax: 7.00%

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Release 3.10

Mon 03 Dec 2002  
EXT Date: 12/07/02  
PROJECT NOTES

U.S. Army Corps of Engineers  
PROJECT SUBJECT: Savannah River Fish Bypass Sys - Savannah River Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft

TIME 10:23:24  
TITLE PAGE 2

This revised estimate incorporates the latest changes to the fish ladder preliminary designs and uses a 3 percent slope for the fish ladders. The estimate is based on the drawings and specifications dated November 2002.

LABOR ID: 650602 EQUIP ID: 800395

Currency is Dollars

CREW ID: 650602 UFB ID: 50065A

How 02 Dec 2002  
Eff. Date 12/03/02  
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U.S. Army Corps of Engineers  
PROJECT SLOJ2E: Savannah Bluff Fish Bypass Sys - Savannah Bluff Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft

TIME 10:23:24  
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| PROJECT OWNER SUMMARY - Sub-Feat.....3    |              |
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| DETAILED ESTIMATE                         | DETAIL PAGE  |
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| 01. Overhead Items - AA.....?             |              |
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| 02. Fish Facilities at Dams               |              |
| 41. Fishways and Ladders                  |              |
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| 03. Concrete Structures.....5             |              |
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Mon 02 Dec 2002  
EXT. DATE 12/01/02

U.S. Army Corps of Engineers  
PROJECT SLD37F Savannah River Fish Bypass Sys - Savannah River Lagoon & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft  
\*\* PROJECT OWNER SUMMARY - Contract (Rounded to 100's) \*\*

TIME 10:23:24  
SUMMARY PAGE 1

|                          | QUANTITY | DOM | CONTRACT  | ESCALATION | CONTINGEN | SION    | TOTAL COST | UNIT COST |
|--------------------------|----------|-----|-----------|------------|-----------|---------|------------|-----------|
| 09 Horseshoe Fish Ladder |          |     | 2,725,500 | 130,800    | 714,100   | 205,300 | 3,775,700  |           |

LABOR ID: GAGE02

EQUIP ID: RS0335

Currency in DOLLARS

CPEN ID: GAGE02 DRB ID: SAMP5A

Mon 01 Dec 2002  
Eff. Date 12/03/02

U.S. Army Corps of Engineers  
PROJECT SLDJEF: Savannah Barge Fish Bypass Sys - Savannah Sluff Lock & Dam  
Savannah Lock & Dam, Fish Ladders Final Draft  
\*\* PROJECT ORDER SUMMARY - Feature (Rounded to 100's) \*\*

TIME 10:13:24  
SUMMARY PAGE 2

|                              | QUANTITY | UNIT | CONTRACT  | ESCALATE | CONTINGEN | SIGM    | TOTAL COST | UNIT COST |
|------------------------------|----------|------|-----------|----------|-----------|---------|------------|-----------|
| 09 Horseshoe Fish Ladder     |          |      |           |          |           |         |            |           |
| 09.05 Fish Facilities at Dam | 1.00     | EA   | 2,725,500 | 140,600  | 714,100   | 205,300 | 4,775,700  | 3775712   |
| TOTAL Horseshoe Fish Ladder  |          |      | 2,725,500 | 140,600  | 714,100   | 205,300 | 4,775,700  |           |

LABOR ID: 000002

EQ/UP ID: 000135

CURRENCY in DOLLARS

CRPW ID: 000502 OFB ID: SANS5A

Mon 02 Dec 2002  
EXT. DATE 12/01/02

U.S. Army Corps of Engineers  
PROJECT SJ0327 Savannah Bird Fish Refuge SWS - Savannah Bird Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft  
\*\* PROJECT ORDER SUMMARY - Sub-Total (Rounded to 100's) \*\*

TIME 10:23:14  
SUMMARY PAGE 3

|                               | QUANTITY | UNIT | CONTRACT  | ESCALATED | CONTINGEN | SION    | TOTAL COST | UNIT COST |
|-------------------------------|----------|------|-----------|-----------|-----------|---------|------------|-----------|
| 04 Horseshoe Fish Ladder      |          |      |           |           |           |         |            |           |
| 04.06 Fish Facilities at Dams |          |      |           |           |           |         |            |           |
| 09.06.44 Fishways and Ladders | 1.00     | EA   | 2,725,500 | 140,400   | 714,100   | 205,300 | 3,775,700  | 3775712   |
| TOTAL Fish Facilities at Dams | 1.00     | EA   | 2,725,500 | 140,400   | 714,100   | 205,300 | 3,775,700  | 3775712   |
| TOTAL Horseshoe Fish Ladder   |          |      | 2,725,500 | 140,400   | 714,100   | 205,300 | 3,775,700  |           |

LABOR ID: GAGE02

EQUIP ID: EQU055

CURRENCY IN DOLLARS

CREW ID: GAGE02 OFF ICE: SANSAN

Mon 03 Dec 2002  
Eff. Date 12/03/02

U.S. Army Corps of Engineers  
PROJECT S1032F: Savannah Bluff Fish Byways Sys - Savannah Bluff Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft  
\*\* PROJECT OWNER SUMMARY - Element (Rounded to 100%) \*\*

TIME 10:23:28  
SUMMARY PAGE 5

|                                              | QUANTITY | UOM | CONTRACT  | ESCALATE | CONTINGEN | SIGM    | TOTAL COST | UNIT COST |
|----------------------------------------------|----------|-----|-----------|----------|-----------|---------|------------|-----------|
| 00 Harborside Fish Ladder                    |          |     |           |          |           |         |            |           |
| 09.06 Fish Facilities at Dams                |          |     |           |          |           |         |            |           |
| 09.06.44 Fishways and Ladders                |          |     |           |          |           |         |            |           |
| 09.06.44.02 Excavation, Riprap and Siltwork: | 1.00     | EA  | 1,498,500 | 71,900   | 392,800   | 112,900 | 2,075,900  | 2075857   |
| 09.06.44.03 Concrete Structures              | 2.00     | EA  | 1,227,100 | 50,900   | 321,500   | 92,400  | 1,699,900  | 849937.45 |
| TOTAL Fishways and Ladders                   | 1.00     | EA  | 2,725,500 | 130,800  | 714,300   | 205,300 | 3,775,700  | 3775712   |
| TOTAL Fish Facilities at Dams                | 1.00     | EA  | 2,725,500 | 130,800  | 714,300   | 205,300 | 3,775,700  | 3775712   |
| TOTAL Harborside Fish Ladder                 |          |     | 2,725,500 | 130,800  | 714,300   | 205,300 | 3,775,700  |           |

LABOR ID: 0A0602

EQUIP ID: RG0195

Currency in DOLLARS

CRPW ID: 0A0602 UPB ID: SAMESA



Mon 02 Dec 2002  
EAT Date 12/01/02

U.S. Army Corps of Engineers  
PROJECT SLD32F: Savannah River Fish Passage Sys - Savannah Sluice Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft  
\*\* PROJECT INDIRECT SUMMARY - Contract (Rounded to 100's) \*\*

TIME 10:24:24  
SUMMARY PAGE 2

|                          |  | QUANTITY UOM | DIRECT    | OVERHEAD | HOME OPC | PROFIT  | BOND/INS | TOTAL COST | UNIT COST |
|--------------------------|--|--------------|-----------|----------|----------|---------|----------|------------|-----------|
| 09 Horseshoe Fish Ladder |  |              | 2,102,600 | 235,200  | 70,100   | 245,600 | 74,200   | 2,725,500  |           |

LAB008 ID: GAVE02      EQUIP ID: ES0185

Increased in COLLARS

CRNN ID: GAVE02      WEB ID: SAMP5A

Nov 03 Dec 2002  
Eff. Date 12/03/02

U.S. Army Corps of Engineers  
PROJECT SITES: Savannah River Fish Bypass Sys - Savannah River Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft  
\*\* PROJECT INDIRECT SUMMARY - Features (Rounded to 100's) \*\*

TIME 10:23:21  
SUMMARY PAGE 6

|                               | QUANTITY | UNIT | DIRECT    | OVERHEAD | HOME OFC | PROFIT  | BOND/INS | TOTAL COST | UNIT COST |
|-------------------------------|----------|------|-----------|----------|----------|---------|----------|------------|-----------|
| 0.0 Horsehoe Fish Ladder      |          |      |           |          |          |         |          |            |           |
| 09.06 Fish Facilities At Dams | 1.00     | EA   | 2,102,600 | 233,200  | 70,100   | 245,100 | 74,200   | 2,725,500  | 2725500   |
| TOTAL Horsehoe Fish Ladder    |          |      | 2,102,600 | 233,200  | 70,100   | 245,100 | 74,200   | 2,725,500  |           |

LABOR ID: 0A0602

EQUIP ID: R01072

STATEMENT OF WORK

CREW ID: 0A0602 UPR ID: 54495A

Mon 02 Dec 2002  
EXT. DATE 12/01/02

U.S. Army Corps of Engineers  
PROJECT SUBJECT: Savannah River Fish Bypass Sys - Savannah River Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft  
\*\* PROJECT INDIRECT SUMMARY - SUB-Total (Rounded to 100's) \*\*

TIME 10:23:14  
SUMMARY PAGE 7

|                               | QUANTITY | UOM | DIRECT    | OVERHEAD | HOME OFF | PROFIT  | EXCHG/INS | TOTAL COST | UNIT COST |
|-------------------------------|----------|-----|-----------|----------|----------|---------|-----------|------------|-----------|
| 09 Holmewood Fish Ladder      |          |     |           |          |          |         |           |            |           |
| 08.06 Fish Facilities at Dams | 1.00     | EA  | 2,102,600 | 233,200  | 70,100   | 245,400 | 74,200    | 2,725,500  | 2725506   |
| 09.06.44 Fishways and Ladders | 1.00     | EA  | 2,102,600 | 233,200  | 70,100   | 245,400 | 74,200    | 2,725,500  | 2725506   |
| TOTAL Fish Facilities at Dams |          |     | 2,102,600 | 233,200  | 70,100   | 245,400 | 74,200    | 2,725,500  |           |
| TOTAL Holmewood Fish Ladder   |          |     |           |          |          |         |           |            |           |

LABOR ID: GAGE02 EQUIP ID: E603MS

Currency in DOLLARS

CHEN ID: GAGE02 WEB ID: SAMP54

Mon 01 Dec 2002  
EFF. DATE 12/01/02

U.S. Army Corps of Engineers  
PROJECT SLO32F: Savannah River Fish Bypass Sys - Savannah River Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft  
\*\* PROJECT INDIRECT SUMMARY - Element (Rounded to 100's) \*\*

TIME 10:28:28  
SUMMARY PAGE 8

|                                              | QUANTITY | UNIT | DIRECT    | OVERHEAD | HOME DEC | PROFIT  | BOND/INS | TOTAL COST UNIT COST |
|----------------------------------------------|----------|------|-----------|----------|----------|---------|----------|----------------------|
| 08 Horseshoe Fish Ladder                     |          |      |           |          |          |         |          |                      |
| 09.06 Fish Facilities at Dams                |          |      |           |          |          |         |          |                      |
| 09.06.44 Fishways and Ladders                |          |      |           |          |          |         |          |                      |
| 09.06.44.02 Excavation, Piping and Miterwork | 1.00     | EA   | 1,155,000 | 325,200  | 38,500   | 114,200 | 40,200   | 1,494,500            |
| 09.06.44.03 Concrete Structures              | 2.00     | EA   | 946,000   | 305,000  | 31,500   | 110,200 | 33,400   | 1,227,100            |
|                                              |          |      |           |          |          |         |          | 813526.10            |
| TOTAL Fishways and Ladders                   | 1.00     | EA   | 2,102,600 | 733,200  | 70,100   | 245,400 | 74,200   | 2,725,500            |
|                                              |          |      |           |          |          |         |          | 2725506              |
| TOTAL Fish Facilities at Dams                | 1.00     | EA   | 2,102,600 | 733,200  | 70,100   | 245,400 | 74,200   | 2,725,500            |
|                                              |          |      |           |          |          |         |          | 2725506              |
| TOTAL Horseshoe Fish Ladder                  |          |      | 2,102,600 | 733,200  | 70,100   | 245,400 | 74,200   | 2,725,500            |

LABOR ID: 0A3602

EQUIP ID: 6G0135

CURRENCY IN DOLLARS

CRW ID: 6A0502 UPR ID: 5AN95A

Mon 02 Dec 2002  
EXT. DATE 12/01/02

PROJECT SLD721 U.S. Army Corps of Engineers  
Savannah Bird Fish Bycatcher Sys - Savannah Sluff Lough & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft  
\*\* PROJECT DIRECT SUMMARY - Contract (Rounded to 100's) \*\*

TIME 10:21:24  
SUMMARY PAGE 9

|                          |  | QUANTITY UCM |  | MANHRS  |  | LABOR EQUIPMENT MATERIAL |  | OTHER   |  | TOTAL COST UNIT COST |  |
|--------------------------|--|--------------|--|---------|--|--------------------------|--|---------|--|----------------------|--|
| 99 Horseshoe Fish Ladder |  | 33,300       |  | 741,000 |  | 571,300                  |  | 760,700 |  | 2,102,600            |  |

LABRE ID: GAN002 EQUIP ID: EQ0185

Currency in DOLLARS

CREW ID: GAN002 WEB ID: SANS1A

Mon 01 Dec 2002  
ZFL Date 12/01/02

U.S. Army Corps of Engineers  
PROJECT SLIDING: Savannah River Fish Bypass Sys - Savannah River Lock & Dam  
SAVANNAH LOCK & DAM, Fish Ladder Final Draft  
\*\* PROJECT DIRECT SUMMARY - Feature (Rounded to 100's) \*\*

TIME 10:23:24  
SUMMARY PAGE 10

|                          |                             | QUANTITY UOM | MANHRS | LAGER EQUIPMNT | MATERIAL | OTHER   | TOTAL COST | UNIT COST |
|--------------------------|-----------------------------|--------------|--------|----------------|----------|---------|------------|-----------|
| By Horseshoe Fish Ladder |                             |              |        |                |          |         |            |           |
| 04.06                    | Fish Facilities at Dam      | 1.00         | EA     | 33,300         | 741,000  | 571,300 | 760,700    | 29,600    |
|                          |                             |              |        |                |          |         |            | 2,102,600 |
|                          | TOTAL Horseshoe Fish Ladder |              |        | 33,300         | 741,000  | 571,300 | 760,700    | 2,102,600 |

LABOR ID: 000002 EQUIP ID: 000005

CURRENCY IN DOLLARS

CREW ID: 000002 UPR ID: 000005

Mon 03 Dec 2002  
Est. Date 12/01/02

U.S. Army Corps of Engineers  
PROJECT SLD32F: Savannah River Fish Bypass Sys - Savannah Sluff Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft.  
\*\* PROJECT DIRECT SUMMARY - Sub-Feet (Rounded to 100's) \*\*

TIME 10:28:24  
SUMMARY PAGE 11

|                               | QUANTITY | UOM | MANHRS | LABOR EQUIPMT MATERIAL | OTHER   | TOTAL COST | UNIT COST |
|-------------------------------|----------|-----|--------|------------------------|---------|------------|-----------|
| 09 Hogeshoe Fish Ladder       |          |     |        |                        |         |            |           |
| 09.06 Fish Facilities at Dams |          |     |        |                        |         |            |           |
| 09.06.44 Fishways and Ladders | 1.00     | EA  | 33,300 | 741,000                | 571,300 | 760,700    | 39,600    |
|                               |          |     |        |                        |         |            | 2,102,600 |
|                               |          |     |        |                        |         |            | 2102610   |
| TOTAL Fish Facilities at Dams | 1.00     | EA  | 33,300 | 741,000                | 571,300 | 760,700    | 39,600    |
|                               |          |     |        |                        |         |            | 2,102,600 |
|                               |          |     |        |                        |         |            | 2102610   |
| TOTAL Hogeshoe Fish Ladder    |          |     | 33,300 | 741,000                | 571,300 | 760,700    | 39,600    |
|                               |          |     |        |                        |         |            | 2,102,600 |

LABOR ID: GAN002 EQUIP ID: E00315

Difference in Dollars

CRSN ID: GAN002 UEN ID: SAN05A





Mon 03 Dec 2002  
ERC Date 12/04/02  
DETAILED ESTIMATE

U.S. Army Corps of Engineers  
PROJECT SLD32F Savannah Bluff Flap Bypass SW - Savannah Bluff Lock & Dam  
Savannah Lock & Dam, Flap Ladder Final Draft  
Project Distributed Costs

TIME 10:23:24  
DETAIL PAGE 1

| 0.01. Prime Marine Contractor            |                                             |                 |       |      |       |      |         |      |         |
|------------------------------------------|---------------------------------------------|-----------------|-------|------|-------|------|---------|------|---------|
| 0.01. Prime Marine Contractor            |                                             |                 |       |      |       |      |         |      |         |
| 0.01. 0. Overhead Items - AA             |                                             |                 |       |      |       |      |         |      |         |
| M CIV <01500 1101 > Field Office Trailer |                                             |                 |       |      |       |      |         |      |         |
| USR                                      | <01500 1102 > Fencing & Storage Area        | 8.00 MCM N/A    | 0.00  | 0.00 | 0.00  | 0.00 | 294.25  | 0.00 | 294.25  |
|                                          |                                             |                 |       |      |       |      | 2,354   | 0    |         |
| USR                                      | <01500 1103 > Office Supplies               | 700.00 LF N/A   | 0.00  | 0.00 | 0.00  | 0.00 | 3.71    | 0.00 | 3.71    |
|                                          |                                             |                 |       |      |       |      | 2,247   | 0    | 2,597   |
| USR                                      | <01500 0501 > Contract Closeout             | 8.00 MCM N/A    | 0.00  | 0.00 | 0.00  | 0.00 | 133.75  | 0.00 | 133.75  |
|                                          |                                             |                 |       |      |       |      | 1,070   | 0    |         |
| MIL                                      | <01710 1111 > Subria Removal & Disposal     | 1.00 MCM N/A    | 0.00  | 0.00 | 0.00  | 0.00 | 1514.00 | 0.00 | 1514.00 |
|                                          |                                             |                 |       |      |       |      | 1,514   | 0    |         |
| USR                                      | <01710 1112 > Continuous Cleanup            | 400.00 CSF URAB | 31.25 | 0.22 | 4.85  | 9.04 | 5.58    | 3.00 | 5.58    |
|                                          |                                             |                 |       | 89   | 1,860 | 15   | 749     | 0    | 2,625   |
| USR                                      | <01710 2112 > Final Job Clean-Up            | 8.00 MCM N/A    | 0.00  | 0.00 | 0.00  | 0.00 | 350.00  | 0.00 | 350.00  |
|                                          |                                             |                 |       |      |       |      | 2,800   | 0    |         |
| M MIL                                    | <01910 1201 > General Superintendent (S.H.) | 1.00 LS N/A     | 0.00  | 0.00 | 0.00  | 0.00 | 1514.00 | 0.00 | 1514.00 |
|                                          |                                             |                 |       |      |       |      | 1,514   | 0    |         |
| M MIL                                    | <01910 1202 > Civil Superintendent (S.H.)   | 8.00 MCM N/A    | 0.00  | 0.00 | 0.00  | 0.00 | 5300.00 | 0.00 | 5300.00 |
|                                          |                                             |                 |       |      |       |      | 42,400  | 0    |         |
| M MIL                                    | <01910 1105 > Timekeeper                    | 8.00 MCM N/A    | 0.00  | 0.00 | 0.00  | 0.00 | 5000.00 | 0.00 | 5000.00 |
|                                          |                                             |                 |       |      |       |      | 40,000  | 0    |         |
| M MIL                                    | <01910 4201 > Chief Planning Engineer       | 2.00 MCM N/A    | 0.00  | 0.00 | 0.00  | 0.00 | 1200.00 | 0.00 | 1200.00 |
|                                          |                                             |                 |       |      |       |      | 9,600   | 0    |         |
| M MIL                                    | <01910 4202 > Quality Control Engineer      | 8.00 MCM N/A    | 0.00  | 0.00 | 0.00  | 0.00 | 4200.00 | 0.00 | 4200.00 |
|                                          |                                             |                 |       |      |       |      | 8,400   | 0    |         |
| M MIL                                    | <01910 4309 > Project Engineers             | 2.00 MCM N/A    | 0.00  | 0.00 | 0.00  | 0.00 | 4700.00 | 0.00 | 4700.00 |
|                                          |                                             |                 |       |      |       |      | 9,400   | 0    |         |
| USR                                      | <01910 5101 > Chief Purchasing Agent        | 1.00 MCM N/A    | 0.00  | 0.00 | 0.00  | 0.00 | 3900.00 | 0.00 | 3900.00 |
|                                          |                                             |                 |       |      |       |      | 8,900   | 0    |         |
| USR                                      | <01913 1001 > Temporary Tower               | 8.00 MCM N/A    | 0.00  | 0.00 | 0.00  | 0.00 | 428.00  | 0.00 | 428.00  |
|                                          |                                             |                 |       |      |       |      | 3,424   | 0    |         |
| USR                                      | <01913 2001 > Temporary Water               | 8.00 MCM N/A    | 0.00  | 0.00 | 0.00  | 0.00 | 235.40  | 0.00 | 235.40  |
|                                          |                                             |                 |       |      |       |      | 1,883   | 0    |         |
| Currency in Dollars                      |                                             |                 |       |      |       |      |         |      |         |
| LABOR ID: 060502 EQUIP ID: 060515        |                                             |                 |       |      |       |      |         |      |         |
| CRSR ID: 060502 URS ID: 060505           |                                             |                 |       |      |       |      |         |      |         |

Mon 31 Dec 2002  
EFF. Date 12/03/02  
DETAILED ESTIMATE

U.S. Army Corps of Engineers  
PROJECT SIB12F: Savannah River Fish Bycatch Sys - Savannah River Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft  
Project Distributed Costs

TIME 10:23:24  
DETAIL PAGE 2

| 0.01. Prime Marine Contracting |               |                                                                   |                  |         |        |          |           |          |         |            |           |
|--------------------------------|---------------|-------------------------------------------------------------------|------------------|---------|--------|----------|-----------|----------|---------|------------|-----------|
|                                | QUANTITY      | UOM                                                               | CREW ID          | CONTENT | MANHRS | LABOR    | EQUIPMENT | MATERIAL | OTHER   | TOTAL COST | UNIT COST |
| USR                            | <01913 3001 > | Temporary Sanitary (See # 34063)                                  | portable Toilets | 8.00    | MON    | N/A      | 0.00      | 0        | 0       | 0          | 107.00    |
| USR                            | <01913 4001 > | Temporary Telephone                                               |                  | 8.00    | MON    | N/A      | 0.00      | 0        | 0       | 0          | 481.50    |
| USR                            | 303500 1102 > | Project Sign(s)                                                   |                  | 1.00    | EA     | N/A      | 0.00      | \$0.00   | \$33.00 | 0.00       | 361.00    |
| USR                            | <01860 1001 > | Testing Adjusting & Balancing                                     |                  | 1.00    | LS     | N/A      | 0.00      | 2000.00  | 0.00    | 0          | 2035.00   |
| USR                            | <01921 6301 > | Maintain Haul Routes                                              |                  | 1.00    | LS     | N/A      | 0.00      | 1000.00  | 350.00  | 214.00     | 1514.00   |
| USR                            | 303500 5100 > | Travel Expense ( 1 Trip Fm MON)                                   |                  | 8.00    | EA     | N/A      | 0.00      | 0        | 0       | 0          | 2,568.00  |
| USR                            | <01922 3001 > | Insurance                                                         |                  | 1.00    | LS     | N/A      | 0.00      | 0.00     | 0       | 0          | 2,354.00  |
| USR                            | <01932 1001 > | Mob and Dem-Mob Offices                                           |                  | 1.00    | LS     | N/A      | 0.00      | 0.00     | 0       | 0          | 4,014.00  |
| USR                            | 301941 3121 > | Storage/Tool Trailer (\$100/MON)                                  |                  | 8.00    | MON    | N/A      | 0.00      | 0.00     | 0       | 0          | 107.00    |
| M MLI                          | <02910 4301 > | Surveyor                                                          |                  | 8.00    | MON    | N/A      | 0.00      | 0        | 0       | 0          | 856.00    |
| USR                            | <02040 1001 > | Schedule Updates (\$400/MON)                                      |                  | 8.00    | MON    | N/A      | 0.00      | 0        | 0       | 0          | 3000.00   |
| MLI                            | >             | TRK, HWY, 4X2, F150, 1/2T, 4300 GVW 4X2 1/2-TON PICK-UP, 4300 GVW |                  | 1.00    | EA     | TR060001 | 0.00      | 375.00   | 0.00    | 26.75      | 401.75    |
| MLI                            | >             | TRK, HWY, 4X2, F250, 3/4T, 4600 GVW 4X2 3/4-TON PICK-UP, 4600 GVW |                  | 1.00    | EA     | TR080003 | 0.00      | 0        | 0       | 0          | 8.41      |
| TOTAL Overhead Items - AA      |               |                                                                   |                  |         |        |          |           |          |         |            |           |
|                                | 99            | 107,350                                                           | 21,663           | 24,130  | 0      | 233,182  | 39147.77  |          |         |            |           |

LABOR ID: 0A0602

EQUIP ID: RS0399

CURRENCY IN DOLLARS

CREW ID: GA0602

UFS ID: SAMP5A

Mon 02 Dec 2002  
Est. Date: 12/01/02  
DETAILED ESTIMATE

U.S. Army Corps of Engineers  
PROJECT SL032P Savannah Bank Fish Bypass Sys - Savannah Bank Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft  
09. Houseline Fish Ladder

TIME 10:23:24  
DETAIL PAGE 3

| 09.05. Fish Facilities at Dams                                                      |  |  |  | QUANTITY FROM CREW ID |  |  |  | OUTPUT MANHOURS |  |  |  | LABOR EQUIPMENT MATERIAL     |  |  |  | OTHER TOTAL COST UNIT COST |  |  |  |
|-------------------------------------------------------------------------------------|--|--|--|-----------------------|--|--|--|-----------------|--|--|--|------------------------------|--|--|--|----------------------------|--|--|--|
| 09.05. Fish Facilities at Dams                                                      |  |  |  | QUANTITY FROM CREW ID |  |  |  | OUTPUT MANHOURS |  |  |  | LABOR EQUIPMENT MATERIAL     |  |  |  | OTHER TOTAL COST UNIT COST |  |  |  |
| 09.06.44.02. Excavation, Slop and Sitework<br>TOTAL Mobilization and Demobilization |  |  |  | 1.00 EA               |  |  |  | 80              |  |  |  | 9,600 8,000 2,000 12,000     |  |  |  | 31,600 31600.00            |  |  |  |
| I USR AA <02225 2155 > Roshing 1166, 4 CY, By Hour                                  |  |  |  | 240.00 HR XXQHU       |  |  |  | 1.00            |  |  |  | 3.00 88.43 135.13 0.00 15.00 |  |  |  | 218.58                     |  |  |  |
| I USR AA <02225 1436 > 2.5 CY, Cleanball                                            |  |  |  | 200.00 HR JOEHW       |  |  |  | 0.86            |  |  |  | 3.00 82.12 62.19 0.00 12.00  |  |  |  | 156.32                     |  |  |  |
| I USR AA <02226 2304 > Scraper, Std. 15 CY, 600 BY HOUR                             |  |  |  | 160.00 HR COGSH       |  |  |  | 1.00            |  |  |  | 1.67 42.08 91.25 0.00 13.00  |  |  |  | 145.33                     |  |  |  |
| MIL AA <02221 2303 > Trench, Hand Exc, Medium Clay                                  |  |  |  | 800.00 CY ULABA       |  |  |  | 0.78            |  |  |  | 1.67 44.88 0.27 0.00 0.00    |  |  |  | 35.16                      |  |  |  |
| I USR AA <02225 4144 > DG BY HOUR                                                   |  |  |  | 120.00 HR XXQNC       |  |  |  | 1.00            |  |  |  | 1.75 38.29 42.30 0.00 12.00  |  |  |  | 97.59                      |  |  |  |
| I USR AA <02225 2505 > 310, 1.25 CY, By Hour                                        |  |  |  | 480.00 HR COGHB       |  |  |  | 1.00            |  |  |  | 1.50 86.80 27.96 0.00 8.00   |  |  |  | 72.76                      |  |  |  |
| AF AA <02221 6004 > Stockpile                                                       |  |  |  | 96000 CY COGTE        |  |  |  | 0.01            |  |  |  | 0.01 0.36 0.47 0.00 0.00     |  |  |  | 0.83                       |  |  |  |
| I USR AA <02225 2505 > 310, 1.75 CY, By Hour                                        |  |  |  | 220.00 HR COELI       |  |  |  | 1.00            |  |  |  | 1.00 25.88 50.00 0.00 0.00   |  |  |  | 75.88                      |  |  |  |
| I AF AA <02225 3263 > Loading to Bags                                               |  |  |  | 96000 CY COBIO        |  |  |  | 22.22           |  |  |  | 0.05 0.98 1.46 0.00 0.00     |  |  |  | 3.44                       |  |  |  |
| <Mod> 3305 > For Each Additional 1 Mile Haul                                        |  |  |  |                       |  |  |  |                 |  |  |  |                              |  |  |  |                            |  |  |  |
| I AF AA <02225 3204 > Hauling 12 CY 12 Miles                                        |  |  |  | 96000 CY COBIO        |  |  |  | 24.89           |  |  |  | 0.04 0.87 1.30 0.00 0.00     |  |  |  | 2.17                       |  |  |  |
| MIL AA < > HARBOR, TRENCH, 25.25'X14'X4.5'                                          |  |  |  | 440.00 HR M10M011     |  |  |  | 1.00            |  |  |  | 0.00 0.00 15.32 0.00 0.00    |  |  |  | 15.32                      |  |  |  |
| I MIL AA < > WORK BASE-S-MED DUTY, 60'X16'X3'                                       |  |  |  | 440.00 HR M10M009     |  |  |  | 1.00            |  |  |  | 0.00 0.00 5.18 0.00 10.00    |  |  |  | 15.18                      |  |  |  |
| MIL AA <06311 8501 > Blocking to Wood, 244-244 80 Pine                              |  |  |  | 600.00 BF ACARC       |  |  |  | 25.00           |  |  |  | 0.05 1.05 0.03 0.43 0.00     |  |  |  | 1.52                       |  |  |  |
| MIL AA <06132 1009 > Heavy Timber Seams                                             |  |  |  | 6000.00 BF ACARS      |  |  |  | 125.00          |  |  |  | 0.04 0.85 0.27 0.79 0.00     |  |  |  | 1.91                       |  |  |  |
| MIL AA <06311 1001 > Concrete Treat, Dosage to 3 #/CF                               |  |  |  | 6.60 MBF N/A          |  |  |  | 0.00            |  |  |  | 0.00 0.00 113.46 0.00 0.00   |  |  |  | 113.46                     |  |  |  |
| PRESERVATIVE Treated Lumber                                                         |  |  |  |                       |  |  |  |                 |  |  |  |                              |  |  |  |                            |  |  |  |
| LABOR ID: GAOUCS EQUIP ID: R0303E                                                   |  |  |  | CURRENCY IN DOLLARS   |  |  |  | CREW ID: GAOUCD |  |  |  | JOB ID: S0005A               |  |  |  |                            |  |  |  |

Mon 02 Dec 2002

Eff. Date 12/01/02

DETAILED ESTIMATE

U.S. Army Corps of Engineers

PROJECT SLD03F: Savannah Bluff Fish Bypass Sys - Savannah Bluff Lock & Dam

09. Horseshoe Fish Ladder

TIME 10:20:34

DETAIL PAGE 4

| 09.06. Fish Facilities at Dams |                                                                   | QUANTITY | UNIT      | CREW ID | OUTPUT | MANHRS | LABOR EQUIPMENT | MATERIAL | OTHER   | TOTAL COST | UNIT COST |
|--------------------------------|-------------------------------------------------------------------|----------|-----------|---------|--------|--------|-----------------|----------|---------|------------|-----------|
| MIL AA <06132 2001 >           | 1wy Back - 6x10 30 Yrd Bins                                       |          |           |         |        | 0.03   | 0.34            | 0.02     | 4.01    | 0.00       | 4.37      |
|                                | Wall Frame Stone/Rwy Tallow Core                                  | 4000.00  | BF        | ACARD   | 137.50 | 56     | 1,470           | 53       | 16,090  | 0          | 37,483    |
| MIL AA <06120 9003 >           | 3/8 X 6 Lag Bolts                                                 |          |           |         |        | 0.17   | 3.50            | 0.06     | 1.82    | 0.00       | 5.38      |
|                                |                                                                   | 500.00   | EA        | ACARA   | 7.50   | 300    | 3,037           | 39       | 1,090   | 0          | 3,427     |
| MIL AA <02102 1103 >           | Cleak and Grub Med Towed to 10' D (25cm) Dia, Cut and Chip        |          |           |         |        | 90.00  | 1740.40         | 1086.65  | 0.00    | 0.00       | 2827.05   |
|                                |                                                                   | 4.00     | ACR COMCA |         | 0.08   | 320    | 6,862           | 4,347    | 0       | 0          | 31,308    |
| AP AA <02102 1108 >            | Clearing - Medium Brush w/o Grub                                  |          |           |         |        | 2.57   | 57.23           | 51.00    | 0.00    | 0.00       | 109.32    |
|                                |                                                                   | 4.00     | ACR COMCE |         | 4.50   | 10     | 229             | 204      | 0       | 0          | 433       |
| MIL AA <02102 1201 >           | Machete Road Spoils, 2 MI Haul (3.2RM) Haul to Dam                |          |           |         |        | 0.74   | 16.70           | 9.11     | 0.00    | 0.00       | 25.81     |
|                                |                                                                   | 200.00   | CY        | COEIT   | 5.38   | 119    | 3,340           | 1,871    | 0       | 0          | 5,162     |
| MIL AA <02221 1801 >           | Trench, Chain Trencher, 1/2 Soil 1' Wide x 4' Deep                |          |           |         |        | 6.03   | 0.73            | 0.26     | 0.00    | 0.00       | 0.99      |
|                                |                                                                   | 7.00     | CY        | CO08B   | 43.00  | 0      | 5               | 2        | 0       | 0          | 7         |
| MIS AA <02221 5001 >           | Backfill Trenches by Hand Without Compaction                      |          |           |         |        | 0.77   | 16.10           | 0.13     | 0.00    | 0.00       | 16.23     |
|                                |                                                                   | 7.00     | CY        | UTABA   | 1.64   | 5      | 133             | 1        | 0       | 0          | 114       |
| L MIL AA <02540 1801 >         | Excavator Control Setting, 4' Wide Jute Mesh, 100 SY (83.8M)      |          |           |         |        | 0.01   | 0.23            | 0.10     | 0.79    | 0.00       | 1.12      |
|                                |                                                                   | 711.00   | SY        | UTABP   | 317.50 | 8      | 366             | 11       | 355     | 0          | 753       |
| L MIL AA <02712 2101 >         | 3' (0.9M) 12 Ga Galv SCL Fence 2" x 4" Mesh, Posts at 3'          |          |           |         |        | 0.09   | 3.95            | 0.84     | 0.73    | 0.00       | 5.52      |
|                                |                                                                   | 1800.00  | LF        | UTABP   | 59.50  | 119    | 1,423           | 1,390    | 1,367   | 0          | 5,625     |
| L USR AA <02261 1001 >         | RLP Exp, 3/8 CY to 1/4 CY Res Random, Dumped from Truck           |          |           |         |        | 0.10   | 2.15            | 4.83     | 19.80   | 0.00       | 26.78     |
|                                |                                                                   | 11700    | TN        | COEIT   | 52.63  | 1,166  | 25,174          | 54,153   | 231,602 | 0          | 310,958   |
| USR AA <02225 1444 >           | Placing Boulders Final Adjustm 50 Ton Motor Crane Assume 50 Cy/Hr |          |           |         |        | 0.10   | 2.25            | 10.38    | 0.00    | 0.00       | 12.63     |
|                                |                                                                   | 2880.00  | CY        | EMAAE   | 41.00  | 289    | 6,451           | 29,900   | 0       | 0          | 36,381    |
| M MIL AA <02261 1005 >         | Relic Stones 3' x 4' Random, Dumped from Truck                    |          |           |         |        | 0.13   | 2.81            | 1.53     | 29.46   | 0.00       | 34.30     |
|                                |                                                                   | 3317.00  | TN        | COEIT   | 33.00  | 416    | 9,334           | 3,059    | 99,677  | 0          | 114,099   |
| M MIL AA <03503 1002 >         | Anchor Ring # Boulders 1/8" Dia Rod w/2" Dia RLVg                 |          |           |         |        | 0.40   | 2.35            | 8.16     | 16.25   | 0.00       | 24.81     |
|                                |                                                                   | 500.00   | EA        | ACARA   | 1.13   | 200    | 4,195           | 78       | 8,122   | 0          | 12,405    |
| L MIL AA <05502 1023 >         | 1" Dia x 12"L Wedge Anchor Expansion Bolt w/Nut & Washer          |          |           |         |        | 0.50   | 10.49           | 0.19     | 9.36    | 0.00       | 19.94     |
|                                |                                                                   | 500.00   | EA        | ACARA   | 2.50   | 250    | 5,243           | 97       | 4,631   | 0          | 9,972     |
| CTV AA <02535 1019 >           | Geotextile Fabric, 150 Mil Thick Non-Woven Polypropylene          |          |           |         |        | 0.03   | 0.56            | 0.03     | 1.89    | 0.00       | 2.48      |
|                                |                                                                   | 12844    | SY        | UTABJ   | 112.50 | 313    | 7,491           | 338      | 24,272  | 0          | 31,501    |
| MIL AA <0810 1001 >            | Mechanical Seeding, 50#/MSY                                       |          |           |         |        | 0.01   | 0.16            | 0.01     | 8.29    | 0.00       | 8.44      |
|                                |                                                                   | 169.40   | CSY       | UTABE   | 194.75 | 1      | 23              | 1        | 1,405   | 0          | 1,428     |

LABOR ID: GAG602

EQUIP ID: RG0395

CURRENCY IN DOLLARS

CREW ID: GAG602

UPR ID: SAMP5A

Mon 02 Dec 2002  
EST. Date 12/01/02  
DETAILED ESTIMATE

U-3. Army Corps of Engineers  
PROJECT SLD327F Savannah Bulk Plant Upgrade Sys - Savannah Bulk Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft  
09. Holstonville Fish Ladder

TIME 10:21:54  
DETAIL PAGE 5

| 09.06. Fish Facilities at Dam                                                                |          |      |       |    |                                                                         |         |         |           |          |          |            |           |         |
|----------------------------------------------------------------------------------------------|----------|------|-------|----|-------------------------------------------------------------------------|---------|---------|-----------|----------|----------|------------|-----------|---------|
|                                                                                              | QUANTITY | UNIT | CHRG  | ID | CONTENT                                                                 | MEMBERS | LABOR   | EQUIPMENT | MATERIAL | OTHER    | TOTAL COST | UNIT COST |         |
| I UBR AA <02830 2005 > Large Power Balancer, Oak Stream,<br>1" Deep                          | 3.50     | ACR  | CODEC |    |                                                                         | 1.32    | 34.03   | 6.34      | 1087.55  | 0.00     | 1127.92    |           |         |
|                                                                                              |          |      |       |    |                                                                         | 3       | 128     | 22        | 3486     | 0        | 3498       | 1127.92   |         |
| DUK AA <02830 8002 > Watering By Truck                                                       | 152.46   | MSE  | CODEC |    |                                                                         | 67.12   | 0.45    | 0.43      | 0.00     | 0.00     | 0.88       |           |         |
|                                                                                              |          |      |       |    |                                                                         | 3       | 69      | 55        | 0        | 0        | 134        | 0.88      |         |
| AF AA <02810 3001 > Sod to Base Level on Prepared<br>Subgrade, by Hand                       | 21.76    | MSE  | CODEC |    |                                                                         | 1.13    | 118.03  | 14.83     | 174.41   | 0.00     | 305.26     |           |         |
|                                                                                              |          |      |       |    |                                                                         | 115     | 2,527   | 323       | 3,799    | 0        | 6,649      | 305.26    |         |
| DUK AA <02830 8002 > Watering By Truck                                                       | 21.78    | MSE  | CODEC |    |                                                                         | 67.12   | 0.45    | 0.43      | 0.00     | 0.00     | 0.88       |           |         |
|                                                                                              |          |      |       |    |                                                                         | 0       | 10      | 9         | 0        | 0        | 19         | 0.88      |         |
| MIL AA <02830 2003 > Mulch, Wood Chips                                                       | 600.00   | SF   | UJARA |    |                                                                         | 242.25  | 0.11    | 0.00      | 1.07     | 0.00     | 1.18       |           |         |
|                                                                                              |          |      |       |    |                                                                         | 3       | 65      | 0         | 641      | 0        | 707        | 1.18      |         |
| L MIL AA <02830 7011 > Guying Trees, 2" to 4" Diameter                                       | 48.00    | EA   | UJARP |    |                                                                         | 5.83    | 13.01   | 5.83      | 6.28     | 0.00     | 25.37      |           |         |
|                                                                                              |          |      |       |    |                                                                         | 30      | 694     | 268       | 326      | 0        | 1,219      | 25.37     |         |
| I MIL AA <02830 7012 > Guying Trees, 6" to 8" Diameter                                       | 24.00    | EA   | UJARP |    |                                                                         | 1.07    | 73.16   | 31.41     | 13.57    | 0.00     | 128.13     |           |         |
|                                                                                              |          |      |       |    |                                                                         | 84      | 1,756   | 754       | 326      | 0        | 2,835      | 128.13    |         |
| I MIL AA <02830 7015 > Trees, 7" to 8" High                                                  | 72.00    | EA   | UJARP |    |                                                                         | 1.25    | 56.52   | 25.11     | 16.28    | 0.00     | 98.93      |           |         |
|                                                                                              |          |      |       |    |                                                                         | 202     | 4,214   | 1,909     | 1,172    | 0        | 7,195      | 98.93     |         |
| TOTAL Excavation, Fillup and Sitework                                                        |          |      |       |    |                                                                         | 14.172  | 323,869 | 396,126   | 405,106  | 39,600   | 1,155.996  |           |         |
| 09.06.03. Concrete Structures                                                                |          |      |       |    |                                                                         |         |         |           |          |          |            |           |         |
| I MIL AA <03520 2121 > CIP Concrete Headwall                                                 | 150.00   | LF   | ALARM |    |                                                                         | 31.06   | 2096.01 | 62.35     | 906.43   | 0.00     | 3065.19    |           |         |
|                                                                                              |          |      |       |    |                                                                         | 0       | 15,000  | 314,401   | 9,353    | 136,025  | 0          | 459,779   | 3065.19 |
| M CIV AA <05651 1209 > 84" x 96" Gates                                                       | 6.00     | EA   | SNRSE |    |                                                                         | 0.06    | 56.00   | 1606.08   | 502.60   | 6525.93  | 0.00       | 8634.61   |         |
|                                                                                              |          |      |       |    | Self Contained Incl AB & GROUT<br>Per Quote from Whippa 11/22/02        | 448     | 12,849  | 4,021     | 52,207   | 0        | 69,077     | 8634.61   |         |
| 0 CIV AA <05651 1211 > 84" Long Stop Log Sets                                                | 1.00     | EA   | SNRSE |    |                                                                         | 0.11    | 41.99   | 917.55    | 287.13   | 12203.35 | 0.00       | 13408.03  |         |
|                                                                                              |          |      |       |    | Self Contained Incl AB & GROUT<br>Per Quote Per Whippa Inc.<br>11/21/02 | 32      | 910     | 287       | 12,203   | 0        | 13,408     | 13408.03  |         |
| MIL AA <05521 1003 > 2" (51mm) Welded Pipe Hcrl, 2-Ball                                      | 230.00   | LF   | SNRSC |    |                                                                         | 31.08   | 0.13    | 3.59      | 0.21     | 26.38    | 0.00       | 30.17     |         |
|                                                                                              |          |      |       |    | 3 1/2 (1.93M) w/Shop Paint, Stair Hcd                                   | 29      | 826     | 47        | 6,067    | 0        | 6,940      | 30.17     |         |
| M MIL AA <15939 1001 > Portable Gate Operator                                                | 1.00     | EA   | MSHND |    |                                                                         | 1.25    | 2.00    | 45.29     | 0.87     | 1390.83  | 0.00       | 3436.93   |         |
|                                                                                              |          |      |       |    | Per Quote from Whippa<br>11/22/02                                       | 2       | 45      | 1         | 2,391    | 0        | 3,437      | 3436.93   |         |
| MIL AA <02411 1004 > Shoring for 40'(13M) Exc, 38 T&F<br>Steel Sheetpiling, Full and Salvage | 100.00   | TON  | CEIDV |    |                                                                         | 0.88    | 9.14    | 205.96    | 102.13   | 729.92   | 0.00       | 1118.01   |         |
|                                                                                              |          |      |       |    |                                                                         | 914     | 20,596  | 18,213    | 72,992   | 0        | 111,601    | 1118.01   |         |

LABOR ID: 040508 EQUIP ID: 850345

Currency in DOLLARS

CREW ID: 040508



| 09.06. Fish Facilities at Dams                         |          |     |         |         |        |                 |          |         |                      |
|--------------------------------------------------------|----------|-----|---------|---------|--------|-----------------|----------|---------|----------------------|
|                                                        | QUANTITY | UOM | CREW ID | CONTENT | MANHRS | LABOR EQUIPMENT | MATERIAL | OTHER   | TOTAL COST UNIT COST |
| MIL AA <03111 5001 > Pylon Reinforce: Metallic, 14 Dwy |          |     |         |         |        |                 |          |         |                      |
| 0.3 #/SF                                               | 108.00   | SF  | ACHMC   | 166.25  | 0.01   | 0.20            | 0.02     | 0.16    | 0.37                 |
|                                                        |          |     |         |         | 17     | 318             | 23       | 258     | 601                  |
| MIL AA <07111 5002 > 6 Mil Polyethylene Vapor Barrier  |          |     |         |         | 0.37   | 5.67            | 0.13     | 3.40    | 9.13                 |
|                                                        | 17.00    | CSF | ACHMA   | 4.63    | 5      | 96              | 2        | 39      | 156                  |
| MIL AA <03111 1003 > Shoring for 25' (8M) Box, 38 HP   |          |     |         |         | 9.70   | 218.45          | 193.17   | 732.83  | 1164.45              |
| Steel Shoring, Full and Salvage                        | 42.53    | TGN | CFIDV   | 0.83    | 412    | 9,229           | 8,215    | 37,014  | 49,518               |
| TOTAL Concrete Structures                              | 2.00     | EA  |         |         | 19,159 | 417,167         | 175,172  | 354,281 | 946,620              |
| TOTAL Horseshoe Fish Ladder                            |          |     |         |         | 33,331 | 741,032         | 571,298  | 760,686 | 2,102,616            |
| TOTAL Savannah Bluff Fish Bypass Sys                   | 1.00     | EA  |         |         | 33,331 | 741,032         | 571,298  | 760,686 | 2,102,616            |

Mon 02 Dec 2002  
REF. Date: 12/01/02

PROJECT CLOSING: Savannah Bluff Fish Ryppass Sys - Savannah Bluff Lock & Dam  
Savannah Lock & Dam, Flm Landed Final Bldg  
\*\* LABOR BACKUP \*\*

TIME 10:24:24  
BACKUP PAGE: 1

| SRC LABOR ID    | DESCRIPTION                    | BASE  | OVERTN |       |      | TZS  | INS   | FRIG | FWL      | RATE | UM    | UPDATE | *** TOTAL *** |       |
|-----------------|--------------------------------|-------|--------|-------|------|------|-------|------|----------|------|-------|--------|---------------|-------|
|                 |                                |       | BASE   | OT    | OT2  |      |       |      |          |      |       |        | DEFAULT       | HOURS |
| MIL B-CARPENTER | Carpenters                     | 14.00 | 0.00   | 38.00 | 1.55 | 0.00 | 20.87 | HR   | 06/20/02 |      | 18.84 |        | 5863          |       |
| MIL B-CENTERS   | Constant Finishers             | 11.34 | 0.00   | 60.00 | 0.00 | 0.00 | 19.05 | HR   | 06/20/02 |      | 12.93 |        | 1293          |       |
| MIL B-DOORFRM   | Eq Oper, Crane/Shop            | 14.07 | 0.00   | 59.00 | 4.80 | 0.00 | 26.31 | HR   | 06/20/02 |      | 21.20 |        | 565           |       |
| MIL B-DOORFLT   | Eq Oper, Light                 | 14.07 | 0.00   | 29.00 | 4.80 | 0.00 | 21.95 | HR   | 06/20/02 |      | 17.02 |        | 120           |       |
| MIL B-DOORFOLD  | Eq Oper, Medium                | 15.60 | 0.00   | 60.00 | 3.80 | 0.00 | 25.68 | HR   | 06/20/02 |      | 17.15 |        | 2139          |       |
| MIL B-DOORFOLD  | Eq Oper, Quiver                | 11.84 | 0.00   | 60.00 | 3.80 | 0.00 | 22.74 | HR   | 06/20/02 |      | 11.00 |        | 399           |       |
| MIL B-LABORER   | Labrers (Semi-Skilled)         | 11.00 | 5.00   | 60.00 | 2.35 | 0.00 | 20.83 | HR   | 06/20/02 |      | 12.46 |        | 1198          |       |
| MIL B-DOORFRM   | File Drivers                   | 14.00 | 0.00   | 50.00 | 1.55 | 0.00 | 22.55 | HR   | 06/20/02 |      | 21.05 |        | 829           |       |
| MIL B-DOORFRM   | Scumen (reinforcing)           | 14.28 | 0.00   | 61.00 | 0.00 | 0.00 | 22.99 | HR   | 06/20/02 |      | 17.95 |        | 1791          |       |
| MIL B-BUILDING  | Sheet Metal Workers            | 16.65 | 0.00   | 20.88 | 3.78 | 0.00 | 24.13 | HR   | 06/20/02 |      | 24.14 |        | 2             |       |
| MIL B-STRUTTING | Truck Drivers, Heavy           | 19.00 | 0.00   | 62.00 | 8.25 | 0.00 | 29.70 | HR   | 06/20/02 |      | 24.06 |        | 372           |       |
| MIL B-TRUCKDRV  | Outside Equip. Op. Heavy       | 14.00 | 0.00   | 29.00 | 2.38 | 0.00 | 21.73 | HR   | 06/20/02 |      | 18.49 |        | 5974          |       |
| MIL B-TRUCKDRV  | Outside Equip. Op. Light       | 14.00 | 0.00   | 60.00 | 3.80 | 0.00 | 22.50 | HR   | 06/20/02 |      | 11.00 |        | 1260          |       |
| MIL B-TRUCKDRV  | Outside Equip. Op. Medium      | 14.00 | 0.00   | 60.00 | 3.80 | 0.00 | 26.32 | HR   | 06/20/02 |      | 17.43 |        | 373           |       |
| MIL B-TRUCKDRV  | Outside Laborer (Semi-Skilled) | 11.00 | 5.00   | 60.00 | 2.35 | 0.00 | 20.83 | HR   | 06/20/02 |      | 11.44 |        | 572           |       |
| MIL B-TRUCKDRV  | Outside Truck Dr. Heavy        | 14.00 | 0.00   | 29.00 | 2.38 | 0.00 | 20.44 | HR   | 06/20/02 |      | 16.19 |        | 889           |       |

LABOR ID: 060502 EQUIP ID: 060195

LABOR ID: 060502

LABOR ID: 060502

LABOR ID: 060502





Mon 02 Dec 2002  
Eff. Date 12/01/02

U.S. Army Corps of Engineers  
PROJECT SLO32P: Savannah Bluff Fish Ryads Sys - Savannah Bluff Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Birt

TIME 10:23:24  
SETTINGS Page 7

\*\*\*\*\* PROJECT SETTINGS \*\*\*\*\*

ESTIMATE TYPE : 3-Creeps with Auto Service

SALES TAX : 7.00%

DATE OF ESTIMATION SCHEDULE : 12/03/02

PROJECT DIRECT COST COLUMNS

|           |         |      |           |          |       |
|-----------|---------|------|-----------|----------|-------|
| Col Type  | H       | L    | E         | M        | U     |
| Rep Width | 9       | 9    | 9         | 9        | 0     |
| Title     | MANHOLE | LAKE | EQUIPMENT | MATERIAL | OTHER |

PROJECT INDIRECT COST COLUMNS

|           |          |          |        |           |          |
|-----------|----------|----------|--------|-----------|----------|
| Col Type  | O        | U        | P      | B         | X        |
| Rep Width | 13       | 13       | 12     | 12        | 0        |
| Title     | OVERHEAD | HOME OFC | PROFIT | SCHE/THIS | (Unused) |

PROJECT OWNER COST COLUMNS

|           |          |          |      |          |          |
|-----------|----------|----------|------|----------|----------|
| Col Type  | E        | C        | U    | X        | X        |
| Rep Width | 13       | 12       | 12   | 0        | 0        |
| Title     | ESCALATE | CONTINEN | SIGN | (Unused) | (Unused) |

PROJECT BREAKDOWN

| PROJECT ID   | Length | Trail | Level    | 2nd View |
|--------------|--------|-------|----------|----------|
|              |        |       | Title    | Order    |
| Level 1 ID : | 2      | .     | Contract | 1        |
| Level 2 ID : | 2      | .     | Feature  | 2        |
| Level 3 ID : | 2      | .     | Sub-Feat | 3        |
| Level 4 ID : | 2      | .     | Element  | 0        |
| Level 5 ID : | 2      | .     | Level 5  | 0        |
| Level 6 ID : | 2      | .     | Level 6  | 0        |

Owner Cost Level : 0

LABOR ID: GA0502

EQUIP ID: B00135

CURRENCY IN DOLLARS

CRPW ID: 000000

UPR ID: 200055

\*\*\* PROJECT SETTINGS \*\*\*

2ND VIEW COLUMNS

|                            |          |          |          |          |          |          |          |          |          |
|----------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Quantity Column Width : 10 |          |          |          |          |          |          |          |          |          |
| Col Type                   | X        | X        | X        | X        | X        | X        | X        | X        | X        |
| Row Width                  | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| Title                      | (Unused) | (Unused) | (Unused) | (Unused) | (Unused) | (Unused) | (Unused) | (Unused) | (Unused) |
| Shadow                     | X        | X        | X        | X        | X        | X        | X        | X        | X        |

DETAIL REPORT FORMATTING

|              |                              |
|--------------|------------------------------|
| PAGE OPTIONS | Page Break Levels : 2        |
|              | Table of Contents Levels : 4 |

0 1 2 3 4 5 6 7

|             |                                       |
|-------------|---------------------------------------|
| ROW OPTIONS | Print Titles at Levels : Y N N Y N N  |
|             | Print Totals at Levels : Y N N Y N N  |
|             | Print Notes at Levels : Y Y Y Y Y Y Y |
|             | Print Unit Cost Row : Y               |
|             | Print Page Footer : X                 |
|             | Show Cost Codes : Y                   |

COLUMNS OPTIONS

|                   |
|-------------------|
| Print Crew Id : Y |
| Crew Output : Y   |
| Unit Cost : Y     |

UPB TITLES

|                            |
|----------------------------|
| No. of Levels to Print : 0 |
| Bracket Titles With : N N  |
| Include titles Notes : N   |

== PROJECT SETTINGS ==

OTHER REPORT FORMATTING

COLUMN TITLES FOR SUMMARY REPORTS

Column 1 OVERHEAD : OVERHEAD  
Column 2 HOME OFC : HOME OFC  
Column 3 PROFIT : PROFIT  
Column 4 BOND/INS : BONDS & INSURANCE  
Column 5 (Unused) : (Unused)

Column 1 ESCALATION : ESCALATION  
Column 2 CONTING : CONTINGENCY  
Column 3 RICH : SUPERVISION, INSPECTION AND OVERHEAD  
Column 4 (Unused) :  
Column 5 (Unused) :

STANDARD COLUMN WIDTHS

Quantity Columns : 10 Round Totals Column : R-Hundreds  
Total cost Columns : 12 Contingency Notes : No  
Unit Cost Columns : 10 Show Project Totals : No

SPECIAL REPORT FORMATTING OPTIONS

Print Alternate ID : (None)  
Show Header at Level : 0  
Display Indirect Markup as : B - Percent of Total  
CSI Sort at Level : (None)

\*\*\* PROJECT SETTINGS \*\*\*

REPORT SELECTION

|                                 |        |                    |       |
|---------------------------------|--------|--------------------|-------|
| Project Settings:               | Y      | Profit Guidelines: | N     |
| Contractor Settings:            | Y      | Measurement Units: | U.S.  |
| Line Listing:                   | N      |                    |       |
| REPORT EVENT TYPE FOR LEVEL (s) |        |                    |       |
|                                 | Direct | Indirect           | Owner |
| Detail:                         | Y      |                    |       |
| Project:                        | Y      | Y                  | Y     |
| Contractor:                     | N      | N                  | N     |
| Division:                       | N      | N                  | N     |
| System:                         | N      | N                  | N     |
| 2nd View:                       | N      | N                  | N     |
| Crew:                           | Y      | N                  | N     |
| Labor:                          | Y      | N                  | N     |
| Equipment:                      | Y      | N                  | N     |
| Prime Labor Cost Level:         | N      |                    |       |

Mon 02 Dec 2002

REF. Date 12/04/02

U.S. Army Corps of Engineers

PROJECT GROUP: Savannah Bluff Fish Bypass Sys - Savannah Bluff Lock & Dam

Savannah Lock & Dam, Fish Locks Final B/M/LT

TIME 10:23:24

SETTINGS PAGE 5

Project Information Request

ESCALATION

CONFIRMENCY

SUPERVISION, INSPECTION AND OVERHEAD

\*\* OWNER, OVERTIME, AND ADJUSTMENTS SETTINGS \*\*

AMOUNT PERCENT BEGIN END BEGIN END

4.80 11/02 07/04 515,150 538,580

25.00

5.75

LABOR ID: GA0602

EQUIP ID: RG0395

CURRENCY in Dollars

CREW ID: GA0602 UPR ID: SP095A

Mon 03 Dec 2002  
Exp. Date 12/01/02

U.S. Army Corps of Engineers  
PROJECT SUBOFF: Savannah Bluff Fish Bypass Sys - Savannah Bluff Lock & Dam  
Savannah Lock & Dam, Fish Ladder Final Draft

TIME 10:23:21  
SETTINGS PAGE 6

\*\* CONTRACTOR SETTINGS \*\*

| AMOUNT | ECT | ECT \$ | RISK | DIFF | SIZE | PERIOD | INVEST | ASSIST | SUBCON |
|--------|-----|--------|------|------|------|--------|--------|--------|--------|
|--------|-----|--------|------|------|------|--------|--------|--------|--------|

AA Prima Marine Contractor

|            |       |
|------------|-------|
| OVERHEAD   | 3.00  |
| WORKING PC | 10.00 |
| INSURANCE  | 2.00  |

TAMUR ID: GAO002

EQUIP ID: E00315

CURRENCY in DOLLARS

CREW ID: GAO003 UPG ID: S00056

MON ON DEC 0009  
EFF. DATE: 12/03/02  
ERROR REPORT

U.S. Army Corps of Engineers  
PROJECT SLOOPS: Savannah Bluff Fish Bypass Sys - Savannah Bluff Lock & Dam  
SAVANNAH LOCK & DAM, FISH LADDER FINAL PART

TIME 10:23:24  
ERROR PAGE 7

NO ERRORS DETECTED...

\*\*\* END OF ERROR REPORT \*\*\*

LABOR ID: 060602

ROUTE ID: R00195

CURRENCY IN DOLLARS

CRPW ID: 060602

UPR ID: SPM556



DRAFT

## VI Cost Estimate

### A. Material Quantity Estimate

Listed below is an estimate of major quantities necessary to construct the NSBL&D Fish Bypass System:

| Item       | Description                                      | Units          | Quantity         |
|------------|--------------------------------------------------|----------------|------------------|
| <b>A</b>   | <b>Site Prep &amp; Temporary Works</b>           |                |                  |
|            | Access Roads — <i>See Drawings - Haul Routes</i> | LM             | TBD              |
|            | Barge Unloading Facility — <i>1st Side</i>       | LS             | 1 ✓              |
|            | Temporary Cofferdams                             |                |                  |
|            | Filter Fabric                                    | SY             | 2100             |
|            | Riprap                                           | CY             | 710              |
|            | Earthwork                                        | CY             | 35000            |
|            | Utilities                                        | LS             | 1 ✓              |
|            | Construction Power                               | LS             | 1 ✓              |
|            | Water Control — <i>Pumps</i>                     | LS             | 1 ✓              |
|            | Site Laydown Area — <i>10 EX. 1</i>              | LS             | 1 ✓              |
|            | Temporary Fencing <i>700'</i>                    | LF             | 1400 ✓           |
|            | Erosion Control <i>1000 LF</i>                   | LS             | 1 ✓              |
| <b>B</b>   | <b>Civil Works</b>                               |                |                  |
| <b>B.1</b> | <b>Earth Work &amp; Drainage</b>                 |                |                  |
|            | Clearing & Grubbing                              | Acre           | 4 ✓              |
|            | Earthwork                                        |                |                  |
|            | Excavation                                       | CY             | 53000            |
|            | Disposal                                         | CY             | 58000 ✓          |
|            | Filter Fabric <i>12,744 SY</i>                   | <del>See</del> | <del>11000</del> |
|            | Riprap                                           | CY             | 7400             |
|            | Boulders                                         | EA             | 500              |
|            | Rough Grading                                    | Acre           | 4                |
|            | Fine Grading — <i>See</i>                        | Acre           | 4                |
|            | Canal Access Concrete Paving <i>1000'</i>        | CY             | 56               |
| <b>B.2</b> | <b>Headwater Structure</b>                       |                |                  |
|            | Sheet Piling                                     | <del>90</del>  | 5250             |
|            | Concrete                                         | CY             | 450              |
|            | Reinforcing                                      | Ton            | 15               |
|            | Miscellaneous Steel                              |                |                  |
|            | Handrail                                         | LF             | 230 ✓            |
|            | Grating                                          | Ton            | (1)              |
|            | Miscellaneous Steel Embeds <i>with Gates</i>     | Ton            | (1)              |
|            | Slide Gates w/Operators                          | EA             | 8                |
|            | Stop Logs                                        | EA             | (1)              |
| <b>B.3</b> | <b>General</b>                                   |                |                  |
|            | Landscaping <i>LS 1000'</i>                      | LS             | 1 ✓              |
|            | Fencing                                          | LF             | 1400 ✓           |
|            | Access — <i>via Barge</i>                        | LF             | TBD              |
| <b>C</b>   | <b>Electrical Works</b> <i>N/C</i>               | LS             | TBD              |
| <b>D</b>   | <b>Mechanical Works</b> <i>N/C</i>               | NA             | NA               |



## FAX COVER SHEET

DATE 11/25/02

TOTAL PAGES 3

TO Mr. James Walters  
\_\_\_\_\_  
\_\_\_\_\_

FROM Wayne Ewing  
RINKER MATERIALS - DOGWOOD  
5868 COLUMBIA ROAD  
GROVETOWN, GA 30813

PHONE 850-897-5380 PHONE (706) 541-0187

FAX 850-897-5388 FAX (706) 541-9161

REMARKS:

Mr. Walters,  
Conversion factor for both  
Type T and armor is about the  
same at 1.5 tons / cubic yrd.  
Please call if you have any questions  
Thank you  
Wayne Ewing

NOV-20-2002 15:19

RINKER MATERIALS

706 541 9151 P.02/02

# Rinker

MATERIALS™

Southern Aggregates  
5368 Columbia Road  
Grovetown, GA 30813

## Quote Sheet

Customer Name: Titan Corp. Date: 11/25/02  
 Telephone: 850-897-5380 Contact: Mr. James Walters  
 Job Name: New Savannah Bluff/Gish Ladder Job No. V  
 P.O. No. \_\_\_\_\_ County Job In: Richmond County

| Approximate<br>Quantity | Material Description | FOB<br>Plant | FOB<br>Delivered<br>Tandem | FOB<br>Delivered<br>Trailer |
|-------------------------|----------------------|--------------|----------------------------|-----------------------------|
|-------------------------|----------------------|--------------|----------------------------|-----------------------------|

### Requirements

|         |                     |           |  |             |
|---------|---------------------|-----------|--|-------------|
| 11,200T | 62.00T-Typ & Rip Bp | # 12.50/T |  | # 18.50/T ✓ |
| 208 pcs | 4' Dia ± Orman      | # 16.00/T |  | # 28.00/T ✓ |
| 312 pcs | 5' Dia ± Orman      | # 16.00/T |  | # 28.00/T ✓ |
|         |                     |           |  |             |
|         |                     |           |  |             |
|         |                     |           |  |             |
|         |                     |           |  |             |

Above Prices Do Not Include Applicable Sales Tax (es).

Approximate Date For Job to Begin: \_\_\_\_\_

Comments: \_\_\_\_\_

Wayne Ewing  
 Wayne Ewing  
 Division Sales Manager  
 706-541-0187

TOTAL P.02

11-22-2002 10:45AM

FROM AMERICAN CONCRETE INC

TO

18508975388 P.01



P.O. Box 2508 • Augusta, Georgia 30903-2508 • (706) 724-0860 • FAX (706) 724-0340

DATE: November 22, 2002

TO: James Walters  
TITAN CORPORATION  
FAX# 850-897-5388

RE: Savannah Bluff Dam

We are pleased to quote the following prices for the described material(s) F.O.B. to the above job site during normal operating hours, Monday through Friday.

| DESCRIPTION  | PSI  | PRICE PER CUBIC YARD |
|--------------|------|----------------------|
| Mix No. 3000 | 3000 | \$53.25              |
| Mix No. 4000 | 4000 | \$56.75              |

TERMS: \$1.00 per cubic yard discount for payment by the 10<sup>th</sup> prox. of the month following delivery, net 30 days. Prices do not include sales tax. Prices are firm through April 2004.

SPECIAL REQUIREMENTS:

THANK YOU FOR THIS OPPORTUNITY OF QUOTING.

BY: James Hutto  
James Hutto, Sales Manager

4343 Shallowford Road  
Suite H2  
Marietta, GA 30062  
don@southernwater.com

Southern Water Technologies

# Fax

|      |                           |        |            |
|------|---------------------------|--------|------------|
| To:  | Mr. James Walters         | From:  | Don Shoaf  |
| CO:  | Titan Corporation         | Pages: | 3          |
| Fax: | 850-897-5388              | Date:  | 11/22/2002 |
| Re:  | Savannah Bluff Lock & Dam | CC:    |            |

☐ Urgent    ☐ For Review    ☐ Please Comment    ☐ Please Reply    ☐ Please Recycle

James,

Thank you for your patience in regard to the above from Whipps, Inc. The following is the budget quote that you requested for the Corps of Engineering project. This includes eight series 806 slide gates with manual operators, eight stop log grooves or tracks and one set of stop logs, and the portable operator. I guess the thought on item 2 was that there would probably only be a need to close one channel at a time with the stop logs, thus only one set of logs and frames/grooves for each of the eight channels. If this does not meet with your requirements, please let me know and we'll put together a price for the additional 7 sets.

Thanks again, and feel free to call me with any additional questions.

# BUDGET PROPOSAL

## Whipps, inc.

P.O. Box 1058 • 370 South Athol Rd.  
Athol, Massachusetts 01331  
Phone: (978) 249-7924  
Fax: (978) 249-3072

November 21, 2002

**PLEASE REPLY TO:**  
Southern Water Technologies, Inc.  
4343 Shallowford Road  
Bldg. H, Suite 2  
Marietta, GA 30062 USA  
Voice: 770-993-4392  
Fax: 770-998-2430

*Titan Corporation  
1501 Merchants Way  
Niceville, FL 32578  
Attn: James Walters*

Subject: New Savannah Bluff Lock & Dam  
Augusta, GA  
Proposal: Whipps No. 2463

Gentleman:

We are pleased to offer the following proposal for the Slide Gates and Stop Logs on the project referenced above. The equipment we propose to supply is as follows:

### Item # 1

Eight (8) 84" x 96"

Series 806

The Embedded Aluminum Slide Gate will have the following features: aluminum (alloy 6061-T6) construction; UHMW seat/seals; and neoprene seal on the invert of the opening. The frame is designed to be embedded in concrete. The actuator will be a yoke mounted manual operator with a type 304 SS operating stem and clear plastic stem cover.

Estimated Shipping Weight = 699# each

Estimated Price Each = \$6,099.00

Price for (8) Eight = \$48,792.00

### Item # 2

One (1) 84" x 96"

Series 509

Assembly will consist of the following

|                            |                      |
|----------------------------|----------------------|
| Eight (8) Stop Logs,       | 84" wide x 12" high  |
| Eight (8) Stop Log Groove, | 84" wide x 144" high |
| One (1) Lifter             | 84" wide             |

#### Stop Logs:

Extruded Alum. Logs will be 12" high each. Manufactured from 6061-T6 Alum. A specially shaped urethane seal will be attached to the bottom and ends of the log to reduce leakage.

#### Grooves:

Fabricated from Aluminum shapes, embedded frame design. The invert of the frame will be a fabricated channel shape manufactured in 6061-T6 Alum, designed to form a seal surface for the bottom log.

#### Lifter:

The lifting device will come complete with suitable connecting points for crane operation and will be capable of securing and releasing the logs with the use of a lanyard.

Estimated Price for one (1) Complete Assy: \$11,405.00

Whipps, Inc. Proposal # 2463

WATER CONTROL GATES & EQUIPMENT

Item # 3.

## One (1) Drill- Type Portable Operator

The Operator will be a heavy duty electric drill with double pole trigger, reversing switch for full power in forward or reverse. The hold down trigger switch shuts off unit when released. The P-O will be tripod mounted portable electric drill, 115 volt single phase power source. The PO will have factory set, quick release, automatic overload release clutch.

Estimated Price for one (1) Complete Assy: \$3,169.00

This proposal represents our best interpretation of the project plans. Any subsequent revisions may result in a price change.

**DURATION:** Our price is held firm for 60 days from the Proposal date. Please contact our local representative for updated pricing after 60 days.

**TERMS:** Payment terms are net 30 days with no retainer allowance. Interest will be charged on amounts past due at 1-1/2% per month.

**TAXES:** Tax and/or Use Taxes are not included in this proposal and should not be included in any subsequent purchase order.

**DELIVERIES:** The standard delivery of submittal drawings is 4-5 weeks after receipt of written purchase order. The aluminum slide gates and stop logs will ship 12-14 weeks after receipt of approved submittal drawings. We will make every possible effort to coordinate our engineering and manufacturing schedule with your construction schedule. Please contact our local representative for expedited or extended delivery dates.

**FREIGHT:** The price quoted is F.O.B. our factory in Athol, MA with freight allowed to job site. Partial shipments may be provided upon request for an additional charge. Price includes shipment via common carrier with box trailer. Open top truck shipment may be provided upon request for an additional charge. Price does not include unloading at job site.

Please let us know if we can be of further service.

Sincerely,

*Fred Perry*

Fred Perry  
Regional Sales Manager  
Whipps, Inc.

**VOLUME DISCOUNT DISCLAIMER:** The prices shown reflect a volume discount for the total number of gates quoted. Please call if you need to order fewer than the number shown above and we will send a revised proposal.

TABLE A-1, QUARTERLY COST INDEXES BY CWBS FEATURE CODE  
Base Year 1967 = 100

| CWBS - FEATURE CODES                         | Wt % | 1Q02                | 2Q02*               | 3Q02*               | 4Q02*               | 1Q03*               | 2Q03                | 3Q03*               | 4Q03*               |
|----------------------------------------------|------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|                                              |      | 2001<br>(Oct - Dec) | 2002<br>(Jan - Mar) | 2002<br>(Apr - Jun) | 2002<br>(Jul - Sep) | 2002<br>(Oct - Dec) | 2003<br>(Jan - Mar) | 2003<br>(Apr - Jun) | 2003<br>(Jul - Sep) |
| 02 RELOCATIONS                               | 5%   | 520.18              | 525.38              | 528.04              | 532.49              | 535.49              | 539.14              | 542.79              | 546.45              |
| 03 RESERVOIRS                                | 5%   | 578.44              | 581.45              | 585.39              | 589.33              | 593.34              | 597.39              | 601.44              | 605.48              |
| 04 DAMS                                      | 15%  | 509.60              | 515.82              | 519.32              | 522.81              | 525.47              | 529.05              | 532.63              | 536.22              |
| 05 LOCKS                                     | 2%   | 500.87              | 507.09              | 510.53              | 513.96              | 516.55              | 520.07              | 523.59              | 527.11              |
| 06 FISH & WILDLIFE FACILITIES                | 5%   | 499.61              | 505.69              | 509.11              | 512.54              | 515.15              | 518.66              | 522.17              | 525.69              |
| 07 POWER PLANT                               | 10%  | 483.76              | 490.92              | 494.25              | 497.57              | 499.79              | 503.20              | 506.60              | 510.01              |
| 08 ROADS, RAILROADS & BRIDGES                | 10%  | 520.18              | 525.38              | 528.94              | 532.49              | 535.49              | 539.14              | 542.79              | 546.45              |
| 09 CHANNELS & CANALS                         | 3%   | 543.03              | 548.64              | 552.36              | 556.07              | 559.16              | 562.97              | 566.78              | 570.60              |
| 10 BREAKWATER & SEAWALLS                     | 5%   | 539.17              | 547.26              | 550.97              | 554.67              | 557.12              | 560.91              | 564.71              | 568.51              |
| 11 LEVEES & FLOODWALLS                       | 5%   | 523.55              | 530.87              | 534.46              | 538.06              | 540.56              | 544.25              | 547.93              | 551.62              |
| 12 NAVIGATION PORTS & HARBORS                | 10%  | 491.52              | 516.72              | 520.22              | 523.72              | 524.56              | 525.12              | 528.68              | 532.23              |
| 13 PUMPING PLANT                             | 5%   | 476.24              | 483.29              | 486.57              | 489.84              | 492.02              | 495.37              | 498.73              | 502.08              |
| 14 RECREATION FACILITIES                     | 5%   | 476.24              | 483.29              | 486.57              | 489.84              | 492.02              | 495.37              | 498.73              | 502.08              |
| 15 FLOODWAY CONTROL & DIVERSION<br>STRUCTURE | 2%   | 499.61              | 505.69              | 509.11              | 512.54              | 515.15              | 518.66              | 522.17              | 525.69              |
| 16 BANK STABILIZATION                        | 2%   | 519.26              | 525.07              | 528.63              | 532.19              | 535.02              | 538.67              | 542.32              | 545.97              |
| 17 BEACH REPLENISHMENT                       | 2%   | 550.29              | 556.00              | 559.76              | 563.53              | 566.85              | 570.51              | 574.38              | 578.24              |
| 18 CULTURAL RESOURCE PRESERVATION            | 2%   | 476.24              | 483.29              | 486.57              | 489.84              | 492.02              | 495.37              | 498.73              | 502.08              |
| 19 BUILDINGS, GROUNDS & UTILITIES            | 5%   | 476.24              | 483.29              | 486.57              | 489.84              | 492.02              | 495.37              | 498.73              | 502.08              |
| 20 PERMANENT OPERATING EQUIPMENT             | 2%   | 476.24              | 483.29              | 486.57              | 489.84              | 492.02              | 495.37              | 498.73              | 502.08              |
| COMPOSITE INDEX (WEIGHTED AVERAGE)           | 100% | 507.21              | 515.37              | 518.86              | 522.35              | 524.51              | 528.09              | 531.67              | 535.24              |

Note: FY\* indicates data developed based on OMB projections.

[1st QTR = 2 OCT THRU 31 DECI JAN] [2nd QTR = 2 JAN THRU 31 MAR] [3rd QTR = 2 APR THRU 30 JUN] [4th QTR = 2 JUL THRU 30 SEPT] [OCT]



TABLE A-1, QUARTERLY COST INDEXES BY CWBS FEATURE CODE  
Base Year 1967 = 100

| CWBS - FEATURE CODES                         | WT % | 1Q04*               |                     | 2Q04*               |                     | 3Q04*               |                     | 4Q04*               |                     | 1Q05*               |                     | 2Q05*               |                     | 3Q05*               |                     | 4Q05*               |                     |
|----------------------------------------------|------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|                                              |      | 2003<br>(Oct - Dec) | 2004<br>(Jan - Mar) | 2004<br>(Jan - Mar) | 2004<br>(Apr - Jun) | 2004<br>(Apr - Jun) | 2004<br>(Jul - Sep) | 2004<br>(Jul - Sep) | 2004<br>(Oct - Dec) | 2005<br>(Jan - Mar) | 2005<br>(Jan - Mar) | 2005<br>(Apr - Jun) | 2005<br>(Apr - Jun) | 2005<br>(Jul - Sep) | 2005<br>(Jul - Sep) | 2005<br>(Oct - Dec) | 2005<br>(Jan - Mar) |
| 02 RELOCATIONS                               | 5%   | 549.95              | 553.70              | 557.45              | 561.20              | 564.80              | 568.65              | 572.50              | 576.35              | 580.20              | 584.05              | 587.90              | 591.75              | 595.60              | 599.45              | 603.30              | 607.15              |
| 03 RESERVOIRS                                | 5%   | 609.36              | 613.52              | 617.67              | 621.83              | 625.98              | 630.13              | 634.28              | 638.43              | 642.58              | 646.73              | 650.88              | 655.03              | 659.18              | 663.33              | 667.48              | 671.63              |
| 04 DAMS                                      | 15%  | 539.66              | 543.34              | 547.02              | 550.70              | 554.38              | 558.06              | 561.74              | 565.42              | 569.10              | 572.78              | 576.46              | 580.14              | 583.82              | 587.50              | 591.18              | 594.86              |
| 05 LOCKS                                     | 2%   | 530.49              | 534.11              | 537.73              | 541.35              | 544.97              | 548.59              | 552.21              | 555.83              | 559.45              | 563.07              | 566.69              | 570.31              | 573.93              | 577.55              | 581.17              | 584.79              |
| 06 FISH & WILDLIFE FACILITIES                | 5%   | 529.06              | 532.67              | 536.27              | 539.88              | 543.48              | 547.09              | 550.69              | 554.29              | 557.89              | 561.49              | 565.09              | 568.69              | 572.29              | 575.89              | 579.49              | 583.09              |
| 07 POWER PLANT                               | 10%  | 513.28              | 516.78              | 520.28              | 523.78              | 527.28              | 530.78              | 534.28              | 537.78              | 541.28              | 544.78              | 548.28              | 551.78              | 555.28              | 558.78              | 562.28              | 565.78              |
| 08 ROADS, RAILROADS & BRIDGES                | 10%  | 549.95              | 553.70              | 557.45              | 561.20              | 564.80              | 568.65              | 572.50              | 576.35              | 580.20              | 584.05              | 587.90              | 591.75              | 595.60              | 599.45              | 603.30              | 607.15              |
| 09 CHANNELS & CANALS                         | 3%   | 574.25              | 578.17              | 582.09              | 586.00              | 589.91              | 593.82              | 597.73              | 601.64              | 605.55              | 609.46              | 613.37              | 617.28              | 621.19              | 625.10              | 629.01              | 632.92              |
| 10 BREAKWATER & SEAWALLS                     | 5%   | 572.16              | 576.06              | 579.96              | 583.86              | 587.76              | 591.66              | 595.56              | 599.46              | 603.36              | 607.26              | 611.16              | 615.06              | 618.96              | 622.86              | 626.76              | 630.66              |
| 11 LEVEES & FLOODWALLS                       | 5%   | 555.16              | 558.94              | 562.73              | 566.51              | 570.30              | 574.08              | 577.86              | 581.64              | 585.42              | 589.20              | 592.98              | 596.76              | 600.54              | 604.32              | 608.10              | 611.88              |
| 12 NAVIGATION PORTS & HARBORS                | 10%  | 535.64              | 539.30              | 542.95              | 546.60              | 550.25              | 553.90              | 557.55              | 561.20              | 564.85              | 568.50              | 572.15              | 575.80              | 579.45              | 583.10              | 586.75              | 590.40              |
| 13 PUMPING PLANT                             | 5%   | 505.30              | 508.75              | 512.19              | 515.64              | 519.08              | 522.53              | 525.97              | 529.42              | 532.86              | 536.31              | 539.75              | 543.20              | 546.64              | 550.09              | 553.53              | 556.98              |
| 14 RECREATION FACILITIES                     | 5%   | 505.30              | 508.75              | 512.19              | 515.64              | 519.08              | 522.53              | 525.97              | 529.42              | 532.86              | 536.31              | 539.75              | 543.20              | 546.64              | 550.09              | 553.53              | 556.98              |
| 15 FLOODWAY CONTROL & DIVERSION<br>STRUCTURE | 2%   | 529.06              | 532.67              | 536.27              | 539.88              | 543.48              | 547.09              | 550.69              | 554.29              | 557.89              | 561.49              | 565.09              | 568.69              | 572.29              | 575.89              | 579.49              | 583.09              |
| 16 BANK STABILIZATION                        | 2%   | 549.47              | 553.22              | 556.96              | 560.71              | 564.46              | 568.21              | 571.96              | 575.71              | 579.46              | 583.21              | 586.96              | 590.71              | 594.46              | 598.21              | 601.96              | 605.71              |
| 17 BEACH REPLENISHMENT                       | 2%   | 581.95              | 585.92              | 589.88              | 593.85              | 597.81              | 601.78              | 605.75              | 609.71              | 613.68              | 617.65              | 621.62              | 625.59              | 629.56              | 633.53              | 637.50              | 641.47              |
| 18 CULTURAL RESOURCE PRESERVATION            | 2%   | 505.30              | 508.75              | 512.19              | 515.64              | 519.08              | 522.53              | 525.97              | 529.42              | 532.86              | 536.31              | 539.75              | 543.20              | 546.64              | 550.09              | 553.53              | 556.98              |
| 19 BUILDINGS, GROUNDS & UTILITIES            | 5%   | 505.30              | 508.75              | 512.19              | 515.64              | 519.08              | 522.53              | 525.97              | 529.42              | 532.86              | 536.31              | 539.75              | 543.20              | 546.64              | 550.09              | 553.53              | 556.98              |
| 20 PERMANENT OPERATING EQUIPMENT             | 2%   | 505.30              | 508.75              | 512.19              | 515.64              | 519.08              | 522.53              | 525.97              | 529.42              | 532.86              | 536.31              | 539.75              | 543.20              | 546.64              | 550.09              | 553.53              | 556.98              |
| COMPOSITE INDEX (WEIGHTED AVERAGE)           | 100% | 538.68              | 542.35              | 546.02              | 549.69              | 553.36              | 557.03              | 560.70              | 564.37              | 568.04              | 571.71              | 575.38              | 579.05              | 582.72              | 586.39              | 590.06              | 593.73              |

Note: FY\* indicates data developed based on OMB projections.

[1st QTR = 2 OCT THRU 31 DEC] [2nd QTR = 2 JAN THRU 31 MAR] [3rd QTR = 2 APR THRU 30 JUN] [4th QTR = 2 JUL THRU 30 SEPT] [CY]



VALUE ENGINEERING STUDY SUMMARY REPORT  
Prepared for US Army Corps of Engineers

**SAVANNAH HARBOR EXPANSION PROJECT**  
**P2 113006**  
**VES 08-21**

Value Engineering Report No. 1  
5 June 2008

*Report Prepared By:*



**CONCORD**  
PROJECT CONSULTING, INC.

3300 Highlands Parkway  
Suite 175  
Smyrna, Georgia 30082  
Phone 770-431-1826

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**VALUE ENGINEERING TEAM STUDY**


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**DOD SERVICE:** USACE**VE OFFICER:** Charles W. Fore Jr., P.E., CVS**Value Engineering Study Report on****SAVANNAH HARBOR EXPANSION PROJECT  
P2 113006****SAVANNAH, GEORGIA****VES 08-21****5 June 2008****STUDY SPONSOR:**

The U.S. Army Engineering District, Savannah

**VALUE ENGINEERING FIRM NAME:**

Concord Project Consulting, Inc.

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Craig Wiederhold, SAM/SAS, Plan Formulator

Wilbur Wiggins, SAS, Civil Engineer

Larry Keegan, GPA, CH2M Hill

Hope Moorer, GPA, Program Manager

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**VALUE ENGINEERING TEAM STUDY**


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|                                    |                                                                                                                                                        |    |
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| 22                                 | Allow the dredge materials from upstream mitigation areas to be used to build up the USFWS dikes                                                       | 29 |
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**VALUE ENGINEERING TEAM STUDY**

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**PROJECT DESCRIPTION AND BACKGROUND:**

**PROJECT TITLE:** Savannah Harbor Expansion Project (SHEP)  
P2 113006  
VES 08-21

**PROJECT LOCATION:** Savannah, Georgia

**PROJECT PRIMARY PURPOSE:**

The primary purpose of this project is to deepen the Savannah River Harbor which will allow larger ships to carry more cargo into and out of the harbor thereby providing for lower freight costs to the end consumer.

**BACKGROUND:**

In 1997, three years after the project was deepened from -38 feet mlw to -42 feet mlw, the Georgia Ports Authority (GPA) employed Section 203 WRDA 86 to conduct a feasibility study to fast-track the additional deepening of the harbor to at least 48 feet. The study was begun in March 1997 and 15 months later on 10 May 1998, it was submitted along with the EIS, directly to the Secretary of the Army. In August 1999, Congress conditionally authorized \$230 million to deepen the harbor from -42 feet mlw to as deep as -48 feet mlw over a 36-mile length of channel from the ocean entrance across the bar to the upstream terminal. Congressional authorization was contingent however, upon completion of a Tier II Environmental Impact Statement and an updated economic study. It was also stipulated that Congressional approval was contingent upon a final mitigation plan and an incremental analysis of channel depths which themselves are contingent upon the approval of the departments of Commerce and Interior, the Environmental Protection Agency and the Secretary of the Army.

The importance of moving forward with this project was highlighted when the Georgia Ports Authority reported 2.16 million containers moved in 2006, firmly establishing the Port of Savannah as the second-largest container port on the U.S. East Coast and fourth-largest in the nation behind only the West Coast ports of Los Angeles and Long Beach and the East Coast port of New York/New Jersey. The growth marks an impressive 14 percent increase over the previous year and clearly establishes Savannah as a vital East Coast gateway for imports and exports. In the first eight months of Fiscal-Year 2007, the Ports Authority has already reported double digit container growth. The ports increased container volumes and increasing share of regional and national waterborne cargo traffic directly translate into economic activity that ripples throughout the state and region.

### **Public Interest**

This project is under intense public scrutiny for a variety of reasons that are addressed specifically in the documents provided with this package. The proximity of the USFWS Savannah National Wildlife Refuge and the incursion of additional salt water upstream with further deepening is perhaps the largest outstanding issue and is the focal point of the mitigation planning effort. Coastal shoreline erosion is a concern since the federal channel's presence is viewed as the major cause for interruption of the north-south littoral drift. The residents of Tybee Island, itself a federal shore protection project, have urged the USACE to implement regional sediment management to offset the losses. Also, many residents in the low country are worried that additional dredging into a Miocene period clay layer will violate the Floridan aquifer and exacerbate an existing saltwater incursion problem. All of these concerns were studied in great detail under this project.

### **Project Roles**

During the Tier I feasibility study, led by the GPA, the USACE served in an oversight role. Once authorization occurred, the project was officially a federal navigation project and the USACE became the lead federal agency. Since the authorized project was no longer in the feasibility phase but authorized conditionally, a Memorandum of Understanding was crafted and signed by both parties in July 2001 which outlined the respective agency roles and responsibilities. In the case of the Savannah Harbor Expansion, the Corps of Engineers determines the work to be done after consideration of recommendations from the Cooperating Agencies. The GPA is included in this group as a cooperating agency along with the federal environmental agencies. The USACE is responsible for the scope and independent oversight of the GRR/Tier II EIS. Due to federal funding limitations, the lion's share of the GRR funding has been provided by the GPA while the federal funds have been aimed at preparation of the EIS documentation. To date, the GPA has invested \$28 million since the project's inception with the federal government contributing \$6 million.

### **Project Status**

From a planning and project management perspective, the Phase II Feasibility General Reevaluation Report and EIS schedules have been greatly accelerated over the past two years. This can be attributed to the addition of specific technical capabilities made available through the South Atlantic Navigation Center of Expertise and regionalization of division assets. Specifically, through the utilization of planning assets from Mobile District and Engineering technical capabilities provided by the Engineering Research and Development Center, Wilmington and Charleston Districts, the work pace has been significantly increased. The quality of work has been verified through the Independent, Internal Technical Peer Review and External Peer Review. The performance of work related to the study has also been greatly influenced by the addition of private contractor capabilities such as the case with the development of the project economics with Gulf Engineers and Contractors and more recently with the addition of David Miller and Associates, the firm contracted through the Mobile District to prepare the General Reevaluation Report Document.

To deepen the Savannah Harbor many real issues and perceived issues must be addressed before the project should proceed. These issues are being or have been studied by the Project Delivery Team (PDT) and have been reviewed by various governmental agencies and private concerns that have an interest in this project. The issues include, and have not been limited to, disposal of desirable dredge material near Tybee Island to reduce potential impacts caused by deepening the channel on the beach, Cadmium in the clay soils located in the ship channel, water quality at the City of Savannah water intake structure located at the Abercorn Creek intake in Effingham County, improvement of water quality within the Wildlife Refuge area, the amount or level of dissolved oxygen in the water, ability for fish to move up the river above the New Savannah Bluff Lock and Dam near Augusta, Georgia. To address these issues numerous mitigation studies with various water flow and ship simulations studies were considered and developed by the PDT.

As a result of many studies and meeting, the PDT has focused on addressing the issues noted above by: (1) adding a system to allow fish to migrate to the water above New Savannah Bluff Lock and Dam, (2) improving the quality of water for the City of Savannah at Abercorn intake structure, (3) installing a diversion structure in Savannah River at McCoy's Cut to push water into the cut, (4) Plugging Rifle Cut, (5) realigning middle river, (6) removing the existing Tide Gates and abutments, (7) building a submerged sill downstream of the existing Tide Gate and allowing the area between the existing Tide Gate and the new submerged sill to silt in, (8) adding dissolved oxygen generators at Mulberry Grove and at the existing Tide Gate location, (9) the purchase of land for wildlife mitigation and (10) the disposal of new work dredged materials into the near shore zone off of Tybee Island.

#### **SUMMARY OF VALUE ENGINEERING STUDY:**

The proposed total savings at the completion of the Value Engineering Study was \$34,221,436.



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## VALUE ENGINEERING TEAM STUDY

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### Executive Summary

The Value Engineering Study was conducted at Desoto Hilton Hotel in Savannah, Georgia on May 20-22, 2008. The study was based on the most current documents. The VE team was comprised of members from Wilmington, Charleston, and Savannah Districts U.S. Army Corps of Engineers, Georgia DOT, and Concord Project Consulting, Inc. and associated consultants.

Value Engineering (VE) is a process used to study the functions a project is to achieve. The VE Team took a critical look at how these functions are proposed to be met and it identified alternative ways to achieve the equivalent function while increasing the value and the benefit ratio of the project. In the end, it is hoped that the project will realize a reduction in cost, but increased value is the focus of the process, rather than simply reducing cost. The project was studied using the Corps of Engineers standard Value Engineering (VE) methodology, consisting of five phases:

Information Phase: The Team studied drawings, figures, descriptions of project work, and cost estimates to fully understand the work to be performed and the functions to be achieved.

Speculation Phase: The Team speculated by conducting brainstorming sessions to generate ideas for alternative designs. All team members contributed ideas and critical analysis of the ideas was discouraged (see Appendix B).

Analysis Phase: Evaluation, testing and critical analysis of all ideas generated during speculation was performed to determine potential for savings and possibilities for risk. Ideas were ranked by priority for development. Ideas that did not survive critical analysis were deleted.

Development Phase: The priority ideas were developed into written proposals by VE team members during an intensive technical development session. Proposal descriptions, along with sketches, technical support documentation, and cost estimates were prepared to support implementation of ideas. Additional VE Team Comments were included for items of interest that were not developed as proposals, and these comments follow the study proposals.

Presentation Phase: Presentation is a two-step process. First, the VE Study Report will be distributed for review to all appropriate project supporters and decision-makers. Review comments will be coordinated for decision on any proposals recommended by the study report. Final coordination may include a formal Presentation conference for recommendation of actions to be taken on specific VE proposals.

## VALUE ENGINEERING TEAM STUDY

## SUMMARY OF RECOMMENDATIONS/ACTION

| Proposal No. | PROPOSALS                                                                                                        | PROPOSED SAVINGS                         | ACCEPTED OR REJECTED |
|--------------|------------------------------------------------------------------------------------------------------------------|------------------------------------------|----------------------|
| 1            | Consider all cut-off structures/Core to be made out of Geo-tube with a layer of rock over                        | \$0.00                                   |                      |
| 2            | Make all cut-off using rock filled gabions in lieu of rock                                                       | \$11,733,000<br>Cost Add Not Recommended |                      |
| 3            | Re-use concrete from Tide Gate for core of sediment basin sill                                                   | \$770,493                                |                      |
| 4            | Use sheet pile in lieu of rock at McCoy cut for diversion structure                                              | \$16,230,600                             |                      |
| 5            | Re-claim rock from New Cut area, above mean high water, for closure structures                                   | \$384,315                                |                      |
| 6            | Use sand from the southern part of 2A for sand fill at Rifle Cut plug                                            | \$4,039                                  |                      |
| 7            | Use precast concrete and "H" piles for closure structures at McCoy Cut diversion structure                       | \$16,725,900                             |                      |
| 8            | Install piping between DO system and river using tunnels to prevent cutting down or disturbing the ground cover. | \$106,089                                |                      |
| 9            | Placement of material from station 5+250 to 25+000 in the near shore disposal areas                              | COMMENT                                  |                      |

|           |                                                                                                                                                                      |                |  |
|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|--|
| <b>10</b> | Allow clamshell dredging in all dredging areas of this project outside the naturally enriched Cadmium zones and off shore disposal (for dredging during fish window) | <b>COMMENT</b> |  |
| <b>11</b> | Use Military personnel labor for cleaning/clearing Bear Creek                                                                                                        | <b>COMMENT</b> |  |
| <b>12</b> | Utilize pontoon track vehicle for clearing Bear Creek                                                                                                                | <b>COMMENT</b> |  |
| <b>13</b> | Verify that the cost in the estimate for removing the CSS Georgia is correctly identified (shows correct cost)                                                       | <b>COMMENT</b> |  |
| <b>14</b> | Verify the cost in the estimate for removal of debris is correct                                                                                                     | <b>COMMENT</b> |  |
| <b>15</b> | Allow dredging by clam shell during fish windows outside the naturally enriched Cadmium zones and off shore disposal (for dredging during fish window)               | <b>COMMENT</b> |  |
| <b>16</b> | Consider requesting that fish windows are extended or lifted                                                                                                         | <b>COMMENT</b> |  |
| <b>17</b> | Lower elevation of the DO system to reduce added hydraulic related costs                                                                                             | <b>COMMENT</b> |  |
| <b>18</b> | Verify required buffer zone width for DO system                                                                                                                      | <b>COMMENT</b> |  |
| <b>19</b> | Determine if the number of pipes between the DO system (generators) and the river by combining inlet and/or outfalls and be reduced                                  | <b>COMMENT</b> |  |

|           |                                                                                                             |                |  |
|-----------|-------------------------------------------------------------------------------------------------------------|----------------|--|
| <b>20</b> | Use available sand materials from Tide Gate abutments to fill Geo--tubes                                    | <b>COMMENT</b> |  |
| <b>21</b> | Allow the use of Geo--bags to build plugs in lieu of Geo--tubes                                             | <b>COMMENT</b> |  |
| <b>22</b> | Allow the dredge materials from upstream mitigation areas to be used to build up the USFWS dikes            | <b>COMMENT</b> |  |
| <b>23</b> | Consider as part of the mitigation, pumping the dredge material to the underside of the marsh mat           | <b>COMMENT</b> |  |
| <b>24</b> | Consider reducing the width of the outer bar channel from 600' to 500' in width                             | <b>COMMENT</b> |  |
| <b>25</b> | Consider deepening only 500' wide in lieu of 600' wide bottom in outer bar channel using a step arrangement | <b>COMMENT</b> |  |

**VALUE ENGINEERING PROPOSAL**


---

|                     |                                                                                             |                 |        |
|---------------------|---------------------------------------------------------------------------------------------|-----------------|--------|
| <b>PROPOSAL NO:</b> | 1                                                                                           | <b>PAGE NO:</b> | 1 OF 2 |
| <b>DESCRIPTION:</b> | Consider all cut-off structures/core to be made out of Geo--tube with a layer of rock over. |                 |        |

---

**ORIGINAL DESIGN:**

Closure structures for McCoy's Cut (western branch), Rifle Cut and the Sediment Basin sill were constructed of GADOT Type 1 riprap.

**PROPOSED DESIGN:**

Construct closure structures with a Geo--tube core and outer layer of rock

**ADVANTAGES:**

- Possible Cost Savings
- Possible use of dredged material from McCoys Cut for filling
- Easier removal if project does not successfully achieve environmental goals (adaptive management)

**DISADVANTAGES:**

Increased maintenance  
 Difficulty in in-water placement  
 Possible damage from floating debris

**JUSTIFICATION/ADDITIONAL NOTES:** This alternative was evaluated based on information included in U.S. Army Corps of Engineer Publication ERDC/CHL CHETN-II-50, entitled Geo-textile Tube Structures, Guidelines for Contract Specifications, September 2006, and WRP Technical Note HS-RS-3.2, entitled Geo--textile Tube Structures for Wetlands Restoration and Protection, January 1998. Based on these publications, the best case for use of these tubes is in a shallow water (0-3 feet), low tidal range(0-3 feet), low wave energy environment. Although the wave energy is low at the proposed placement locations, currents are strong in these areas and accurate placement would be difficult. The existing depth at McCoy's and Rifle cut is approximately 12 feet below mean lower low water at McCoy's and Rifle Cuts and up to 40 feet below mean lower low water at the Sediment Basin. In addition, the tidal range is over 7 feet in the Savannah area. This project does not meet the criteria required for Geo--textile Tube Applications.

**Further development of this proposal is not recommended.**

VALUE ENGINEERING PROPOSAL

PROPOSAL NO: 1

PAGE NO: 2 OF 2

|                            |       |          |           |       |
|----------------------------|-------|----------|-----------|-------|
| DELETIONS                  |       |          |           |       |
| ITEM                       | UNITS | QUANTITY | UNIT COST | TOTAL |
|                            |       |          |           |       |
|                            |       |          |           |       |
|                            |       |          |           | \$0   |
|                            |       |          |           | \$0   |
|                            |       |          |           | \$0   |
|                            |       |          |           | \$0   |
|                            |       |          |           | \$0   |
|                            |       |          |           | \$0   |
|                            |       |          |           | \$0   |
|                            |       |          |           | \$0   |
| Total Deletions            |       |          |           | \$0   |
| ADDITIONS                  |       |          |           |       |
| ITEM                       | UNITS | QUANTITY | UNIT COST | TOTAL |
|                            |       |          |           |       |
|                            |       |          |           |       |
|                            |       |          |           |       |
|                            |       |          |           |       |
|                            |       |          |           |       |
|                            |       |          |           |       |
|                            |       |          |           | \$0   |
|                            |       |          |           | \$0   |
|                            |       |          |           | \$0   |
|                            |       |          |           | \$0   |
|                            |       |          |           | \$0   |
| Total Additions            |       |          |           | \$0   |
| Net Cost Decrease/Increase |       |          |           | \$0   |
| Mark-ups                   |       | 27.0%    |           | \$0   |
| Total Potential Net Income |       |          |           | \$0   |
|                            |       |          |           |       |
|                            |       |          |           |       |

**VALUE ENGINEERING PROPOSAL****PROPOSAL NO:** 2**PAGE NO:** 1 OF 2**DESCRIPTION:** Make all cut-offs using rock filled gabions in lieu of rock**ORIGINAL DESIGN:**

Closure structures for McCoy's Cut (western branch), Rifle Cut and the Sediment Basin sill were constructed of GADOT Type 1 riprap.

**PROPOSED DESIGN:**

Construct closure structures with a gabions

**ADVANTAGES:**

- Possible Cost Savings
- Decrease in required stone size

**DISADVANTAGES:**

Increased maintenance  
 Difficulty in in-water placement  
 Possible damage of baskets from floating debris  
 Time and labor intensive installation  
 Possible high velocities causing erosion at the toe

**JUSTIFICATION/ADDITIONAL NOTES:** This alternative was evaluated based on information included in U.S. Army Corps of Engineer Publication ERDC TN-EMRRP SR-22 entitled Gabions for Stream-bank Erosion Control, dated May 2000. Although the gabions would install under conditions that are not typical for their use, they were considered to reduce the quantity of large stone that would be required. Costs for this alternative would actually be higher due to purchase of the baskets, assembly of the baskets, and placement and anchoring of the baskets in a sub-aqueous environment.

**This option is not recommended for further consideration.**

**VALUE ENGINEERING PROPOSAL****PROPOSAL NO: 2****PAGE NO: 2 OF 2**

| <b>COST ESTIMATE WORKSHEET</b>               |       |          |           |               |
|----------------------------------------------|-------|----------|-----------|---------------|
| PROPOSAL NO. 2                               |       |          |           |               |
|                                              |       |          |           |               |
| <b>DELETIONS</b>                             |       |          |           |               |
|                                              |       |          |           |               |
| ITEM                                         | UNITS | QUANTITY | UNIT COST | TOTAL         |
| Close Western Arm McCoys Cut (Armor)         | tons  | 5,100    | \$170.00  | \$867,000     |
| Close Rifle Cut (GADOT Type 1)               | tons  | 7,000    | \$135.00  | \$945,000     |
| Create Sill at Sediment Basin (GADOT Type 1) | tons  | 60,000   | \$135.00  | \$8,100,000   |
|                                              |       |          |           | \$0           |
|                                              |       |          |           | \$0           |
|                                              |       |          |           | \$0           |
|                                              |       |          |           | \$0           |
|                                              |       |          |           | \$0           |
|                                              |       |          |           | \$0           |
|                                              |       |          |           | \$0           |
|                                              |       |          |           | \$0           |
| Total Deletions                              |       |          |           | \$9,912,000   |
| <b>ADDITIONS</b>                             |       |          |           |               |
|                                              |       |          |           |               |
| ITEM                                         | UNITS | QUANTITY | UNIT COST | TOTAL         |
| Close Western Arm McCoys Cut (Gabions)       | cy    | 3,400    | \$450.00  | \$1,530,000   |
| Close Rifle Cut (Gabions)                    | cy    | 4,700    | \$450.00  | \$2,115,000   |
| Create Sill at Sediment Basin (Gabions)      | cy    | 40,000   | \$450.00  | \$18,000,000  |
|                                              |       |          |           |               |
|                                              |       |          |           |               |
|                                              |       |          |           |               |
|                                              |       |          |           | \$0           |
|                                              |       |          |           | \$0           |
|                                              |       |          |           | \$0           |
|                                              |       |          |           | \$0           |
|                                              |       |          |           | \$0           |
| Total Additions                              |       |          |           | \$21,645,000  |
| Net Cost Decrease/Increase                   |       |          |           | -\$11,733,000 |



### VALUE ENGINEERING PROPOSAL

**PROPOSAL NO:** 3

**PAGE NO:** 1 OF 2

**DESCRIPTION:** Re-use concrete from Tide Gate for core of sediment basin sill.

**ORIGINAL DESIGN:** The original design of the sill for the sediment basin contained 100 percent quarried stone.

**PROPOSED DESIGN:** The proposed design will re-use the demolished concrete from the tide gate structure (piers, catwalk/beams, & wing walls) in the core of the sill for the sediment basin. The concrete will be removed from the tide gate structure, crushed, and have the rebar removed. The concrete will then be placed in the center of the sediment basin sill to serve as the core of the structure. The analysis of this proposal assumes that removal of the tide gate structure will occur. Therefore the only costs included in this analysis are the extra cost to crush the concrete, remove the rebar, and place in the sediment basin sill core.

**ADVANTAGES:**

- Re-using the concrete from the tide gate structure will reduce the amount of quarried stone necessary for the construction of the sediment basin sill.
- Re-using material from a local source will cut down on transportation costs.
- Using smaller diameter material within the center of the sediment basin sill will improve the sediment retention characteristic of the sill.

**DISADVANTAGES:**

- The lower unit weight and smaller size of the crushed concrete versus quarried granite may present problems during construction in an environment with potentially high current velocities.

**JUSTIFICATION/ADDITIONAL NOTES:**

## VALUE ENGINEERING PROPOSAL

**PROPOSAL NO: 3**

**PAGE NO: 2 OF 2**

| <b>COST ESTIMATE WORKSHEET</b>                                  |              |                 |                  |              |  |
|-----------------------------------------------------------------|--------------|-----------------|------------------|--------------|--|
| PROPOSAL NO. 3                                                  |              |                 |                  |              |  |
| Re-use concrete from Tide Gate for core of sediment basin sill. |              |                 |                  |              |  |
|                                                                 |              |                 |                  |              |  |
| <b>DELETIONS</b>                                                |              |                 |                  |              |  |
| <b>ITEM</b>                                                     | <b>UNITS</b> | <b>QUANTITY</b> | <b>UNIT COST</b> | <b>TOTAL</b> |  |
| Type I GaDOT Stone                                              | Tons         | 4,875           | \$135.00         | \$658,125    |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              | Total Deletions |                  | \$658,125    |  |
| <b>ADDITIONS</b>                                                |              |                 |                  |              |  |
| <b>ITEM</b>                                                     | <b>UNITS</b> | <b>QUANTITY</b> | <b>UNIT COST</b> | <b>TOTAL</b> |  |
| Crushed and sorted concrete debris                              | Tons         | 4,875           | \$8.50           | \$41,438     |  |
| Mob & demob                                                     |              | 1               | \$10,000.00      | \$10,000     |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              |                 |                  | \$0          |  |
|                                                                 |              | Total Additions |                  | \$51,438     |  |
| Net Cost Decrease/Increase                                      |              |                 |                  | \$606,688    |  |
|                                                                 | Mark-ups     | 27.0%           |                  | \$163,806    |  |
| Total Potential Net Income                                      |              |                 |                  | \$770,493    |  |
|                                                                 |              |                 |                  |              |  |

**VALUE ENGINEERING PROPOSAL****PROPOSAL NO:** 4**PAGE NO: 1 OF 2****DESCRIPTION:** Use sheet pile in lieu of rock at McCoy's Cut for diversion structure.**ORIGINAL DESIGN:**

The current mitigation plan includes the installation of diversion structures at McCoy's Cut. These structures are designed as follows:

- Opposite McCoy's Cut Entrance: Installation of a 465 foot long rock structure with a top elevation of 0.0 ft mllw
- Adjacent to McCoy's Cut Entrance: Installation of a 140 foot long sheet pile wall with a top elevation of 11.0 ft mllw.

The purpose of these structures is to divert fresh water from the Front River into McCoy's Cut to increase the volume of fresh water in the Middle and Back Rivers.

**PROPOSED DESIGN:**

Replace the proposed 465 foot long rock structure opposite the McCoy's Cut entrance with a 465 foot long sheet pile wall with a top elevation of 11.0 ft mllw.

**ADVANTAGES:**

- Construction cost is reduced by switching to sheet pile from stone.
- Holes can be drilled through the bottom of the wall to allow suspended sediments to travel through the wall instead of into McCoy's Cut

**DISADVANTAGES:**

Potential corrosion of sheet pile wall in brackish water

**JUSTIFICATION/ADDITIONAL NOTES:**

## VALUE ENGINEERING PROPOSAL

PROPOSAL NO: 4

PAGE NO: 2 OF 2

| COST ESTIMATE WORKSHEET                                               |       |          |            |              |
|-----------------------------------------------------------------------|-------|----------|------------|--------------|
| PROPOSAL NO. 4                                                        |       |          |            |              |
| Use sheet pile in lieu of rock at McCoys Cut for diversion structure. |       |          |            |              |
| DELETIONS                                                             |       |          |            |              |
| ITEM                                                                  | UNITS | QUANTITY | UNIT COST  | TOTAL        |
| Diversion structure at entrance to McCoys Cut - stone                 | tons  | 81,000   | \$175.00   | \$14,175,000 |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
| Total Deletions                                                       |       |          |            | \$14,175,000 |
| ADDITIONS                                                             |       |          |            |              |
| ITEM                                                                  | UNITS | QUANTITY | UNIT COST  | TOTAL        |
| Diversion wall at entrance to McCoys Cut                              |       |          |            |              |
| Sheet pile                                                            | LF    | 465      | \$3,000.00 | \$1,395,000  |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
|                                                                       |       |          |            | \$0          |
| Total Additions                                                       |       |          |            | \$1,395,000  |
| Net Cost Decrease/Increase                                            |       |          |            | \$12,780,000 |
| Mark-ups                                                              |       | 27.0%    |            | \$3,450,600  |
| Total Potential Net Income                                            |       |          |            | \$16,230,600 |

### **VALUE ENGINEERING PROPOSAL**

**PROPOSAL NO:** 5

**PAGE NO: 1 OF 2**

**DESCRIPTION:** Re-claim rock from New-Cut area, above mean high water, for closure structures.

**ORIGINAL DESIGN:**

Presently rock for the closure structures is to come from granite quarries in northern Georgia.

**PROPOSED DESIGN:**

The proposal is to use the rock that exists in the New-Cut area and that lies above mean high water elevation in the closure structure at Rifle Cut.

**ADVANTAGES:**

- Construction cost is reduced by eliminating the long haul distance from a quarry near Augusta, GA, for some of the rock.
- The rock at New-Cut is accessible and will require minimal excavation.
- The New-Cut area is accessible by tracked excavation equipment.

**DISADVANTAGES:**

The amount of rock available in New-Cut is unknown at this time.

The quality of the rock in New-Cut is unknown at this time.

Fill material will be needed to backfill any rock excavation if the present elevation is to be maintained.

**JUSTIFICATION/ADDITIONAL NOTES:**

The New-Cut area has been closed for some time. Presently there is no flow through the cut.

It is assumed that 7,000 cubic yards of rock are available in New Cut.

It is assumed that the rock at New-Cut can replace only GA Type 1, not the armor stone.

## VALUE ENGINEERING PROPOSAL

**PROPOSAL NO: 5**

**PAGE NO: 2 OF 2**

| <b>COST ESTIMATE WORKSHEET</b>                                                  |              |                 |                  |              |
|---------------------------------------------------------------------------------|--------------|-----------------|------------------|--------------|
| <b>PROPOSAL NO.</b> 5                                                           |              |                 |                  |              |
| Re-claim rock from New-Cut area, above mean high water, for closure structures. |              |                 |                  |              |
| <b>DELETIONS</b>                                                                |              |                 |                  |              |
| <b>ITEM</b>                                                                     | <b>UNITS</b> | <b>QUANTITY</b> | <b>UNIT COST</b> | <b>TOTAL</b> |
| Rock from quarry - Ga DOT - type 1.                                             | tons         | 7,000           | \$135.00         | \$945,000    |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 | Total Deletions  | \$945,000    |
| <b>ADDITIONS</b>                                                                |              |                 |                  |              |
| <b>ITEM</b>                                                                     | <b>UNITS</b> | <b>QUANTITY</b> | <b>UNIT COST</b> | <b>TOTAL</b> |
| Rock excavated from New Cut area.                                               | tons         | 7,000           | \$91.77          | \$642,390    |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 |                  | \$0          |
|                                                                                 |              |                 | Total Additions  | \$642,390    |
|                                                                                 |              |                 |                  |              |
| Net Cost Decrease/Increase                                                      |              |                 |                  | \$302,610    |
|                                                                                 | Mark-ups     | 27.0%           |                  | \$81,705     |
| Total Potential Net Income                                                      |              |                 |                  | \$384,315    |

**VALUE ENGINEERING PROPOSAL****PROPOSAL NO:** 6**PAGE NO: 1 OF 2****DESCRIPTION:** Use sand from the southern part of DA 2A for sand fill at Rifle Cut plug.**ORIGINAL DESIGN:**

Presently sand for the rock plug at Rifle Cut is to come from disposal areas 12A to 14B.

**PROPOSED DESIGN:**

The proposal is to use the sand that exists in disposal area 2A (DA 2A) that lies in about southern part of the disposal area.

**ADVANTAGES:**

- Construction cost is reduced by shortening the haul distance for sand.
- The sand in DA 2A is accessible and will require minimal excavation.
- The DA 2A sand is accessible by tracked excavation equipment.
- Excavation of sand in DA 2A would increase the available capacity there if needed.

**DISADVANTAGES:**

The amount of sand available in DA 2A is unknown at this time.  
The quality of the sand in DA 2A is unknown at this time.

**JUSTIFICATION/ADDITIONAL NOTES:**

The material could be excavated and hauled to the northern end of the area which is nearest to Rifle Cut. The material would then be barged from there to Rifle Cut. It is assumed that enough suitable sand is available in DA 2A.

VALUE ENGINEERING PROPOSAL

PROPOSAL NO: 6

PAGE NO: 2 OF 2

| COST ESTIMATE WORKSHEET                                                   |       |          |           |           |
|---------------------------------------------------------------------------|-------|----------|-----------|-----------|
| PROPOSAL NO. 6                                                            |       |          |           |           |
| Use sand from the southern part of DA 2A for sand fill at Rifle Cut plug. |       |          |           |           |
| DELETIONS                                                                 |       |          |           |           |
| ITEM                                                                      | UNITS | QUANTITY | UNIT COST | TOTAL     |
| Sand from DA 12A to DA 14B.                                               | cy    | 6,000    | \$21.00   | \$126,000 |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
| Total Deletions                                                           |       |          |           | \$126,000 |
| ADDITIONS                                                                 |       |          |           |           |
| ITEM                                                                      | UNITS | QUANTITY | UNIT COST | TOTAL     |
|                                                                           |       |          |           |           |
| Sand from the southern part of DA 2A.                                     | cy    | 6,000    | \$20.47   | \$122,820 |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
|                                                                           |       |          |           | \$0       |
| Total Additions                                                           |       |          |           | \$122,820 |
| Net Cost Decrease/Increase                                                |       |          |           | \$3,180   |
| Mark-ups                                                                  |       | 27.0%    |           | \$859     |
| Total Potential Net Income                                                |       |          |           | \$4,039   |



**VALUE ENGINEERING PROPOSAL****PROPOSAL NO:** 7**PAGE NO: 1 OF 2****DESCRIPTION:** Use precast concrete and "H" piles for diversion structure at McCoy's Cut**ORIGINAL DESIGN:**

The current mitigation plan includes the installation of diversion structures at McCoy's Cut. These structures are designed as follows:

- Opposite McCoy's Cut Entrance: Installation of a 465 foot long rock structure with a top elevation of 0.0 ft mllw
- Adjacent to McCoy's Cut Entrance: Installation of a 140 foot long sheet pile wall with a top elevation of 11.0 ft mllw.

The purpose of these structures is to divert fresh water from the Front River into McCoy's Cut to increase the volume of fresh water in the Middle and Back Rivers.

**PROPOSED DESIGN:**

Replace the proposed 465 foot long rock structure opposite the McCoy's Cut entrance with a 465 foot long precast concrete wall held in place by "H" piles driven into the river bottom with a top elevation of 11.0 ft mllw.

**ADVANTAGES:**

- Construction cost is reduced by switching to a precast concrete wall from stone.
- Adaptive Management would be easier as panels could be removed and reused if the wall needs to be adjusted.
- Spacers can be placed at the bottom of the wall to allow suspended sediments to travel under the wall instead of into McCoy's Cut.

**DISADVANTAGES:**

- Corrosion of "H" piles in brackish water.
- Settlement of concrete panels into river bottom.

**JUSTIFICATION/ADDITIONAL NOTES:**

VALUE ENGINEERING PROPOSAL

PROPOSAL NO: 7

PAGE NO: 2 OF 2

| COST ESTIMATE WORKSHEET                                                   |       |          |           |              |
|---------------------------------------------------------------------------|-------|----------|-----------|--------------|
| PROPOSAL NO. 7                                                            |       |          |           |              |
| Use precast concrete and "H" piles for diversion structure at McCoy's Cut |       |          |           |              |
| DELETIONS                                                                 |       |          |           |              |
| ITEM                                                                      | UNITS | QUANTITY | UNIT COST | TOTAL        |
| Diversion structure at entrance to McCoy's                                | tons  | 81,000   | \$175.00  | \$14,175,000 |
| Cut - stone                                                               |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
| Total Deletions                                                           |       |          |           | \$14,175,000 |
| ADDITIONS                                                                 |       |          |           |              |
| ITEM                                                                      | UNITS | QUANTITY | UNIT COST | TOTAL        |
| Diversion wall at entrance to McCoy's Cut                                 |       |          |           |              |
| "H" piles @ 3 ft OC                                                       | LF    | 4,000    | \$100.00  | \$400,000    |
| Precast Concrete Panels                                                   | SF    | 6,050    | \$100.00  | \$605,000    |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
|                                                                           |       |          |           | \$0          |
| Total Additions                                                           |       |          |           | \$1,005,000  |
| Net Cost Decrease/Increase                                                |       |          |           | \$13,170,000 |
| Mark-ups 27.0%                                                            |       |          |           | \$3,555,900  |
| Total Potential Net Income                                                |       |          |           | \$16,725,900 |

**VALUE ENGINEERING PROPOSAL****PROPOSAL NO:** 8**PAGE NO: 1 OF 2**

**DESCRIPTION:** Install piping between DO system at Mulberry Grove and river using tunnels to prevent cutting down or disturbing the ground cover.

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**ORIGINAL DESIGN:**

Original plan is to construct piping systems between the river and an upland site located 100 feet or more away to allow for a wooded buffer zone. To reasonably construct this will require an extensive clearing effort which will literally destroy the approved buffer zone.

**PROPOSED DESIGN:**

Proposed design is to use directional boring or tunneling techniques to install 20" diameter HDPE piping in-lieu of the 20" diameter DIP being placed in open cut and cover trenches across the environmental buffer zone.

**ADVANTAGES:**

- Construction cost is slightly reduced by eliminating a majority of the 20" diameter Ductile Iron Piping.
- Eliminates the destruction and re-establishment of the environmental habit buffer zone area.
- Less corrosion and maintenance of HDPE vs. DIP

**DISADVANTAGES:**

There are no foreseen disadvantages with this solution.

**JUSTIFICATION/ADDITIONAL NOTES:**

## VALUE ENGINEERING PROPOSAL

PROPOSAL NO: 8

PAGE NO: 2 OF 2

| COST ESTIMATE WORKSHEET                                                                          |       |          |             |             |
|--------------------------------------------------------------------------------------------------|-------|----------|-------------|-------------|
| PROPOSAL NO. 8                                                                                   |       |          |             |             |
| Install piping between DO system and river using tunnels to prevent disturbing the ground cover. |       |          |             |             |
| DELETIONS                                                                                        |       |          |             |             |
| ITEM                                                                                             | UNITS | QUANTITY | UNIT COST   | TOTAL       |
| Clearing and grubbing                                                                            | acres | 0.7      | \$10,000.00 | \$7,000     |
| Rough grade site                                                                                 | sf    | 30,492.0 | \$2.00      | \$60,984    |
| 20" dia bell end DIP (48 runs x say 125')                                                        | lf    | 6,000    | \$220.00    | \$1,320,000 |
| Trench dewatering                                                                                | days  | 40       | \$150.00    | \$6,000     |
| Re-establishment of buffer vegetation                                                            | acres | 0.7      | \$10,000.00 | \$7,000     |
|                                                                                                  |       |          |             | \$0         |
|                                                                                                  |       |          |             | \$0         |
|                                                                                                  |       |          |             | \$0         |
|                                                                                                  |       |          |             | \$0         |
|                                                                                                  |       |          |             | \$0         |
|                                                                                                  |       |          |             | \$0         |
|                                                                                                  |       |          |             | \$0         |
| Total Deletions                                                                                  |       |          |             | \$1,400,984 |
| ADDITIONS                                                                                        |       |          |             |             |
| ITEM                                                                                             | UNITS | QUANTITY | UNIT COST   | TOTAL       |
| 20" dia HDPE (quote Egan Bro's 843-709-2455)                                                     | lf    | 6,000    | \$220.00    | \$1,320,000 |
|                                                                                                  |       |          |             | \$0         |
|                                                                                                  |       |          |             | \$0         |
|                                                                                                  |       |          |             | \$0         |
|                                                                                                  |       |          |             | \$0         |
|                                                                                                  |       |          |             | \$0         |
|                                                                                                  |       |          |             | \$0         |
|                                                                                                  |       |          |             | \$0         |
|                                                                                                  |       |          |             | \$0         |
| Total Additions                                                                                  |       |          |             | \$1,320,000 |
| Net Cost Decrease/Increase                                                                       |       |          |             | \$80,984    |
| Mark-ups                                                                                         |       | 31.0%    |             | \$25,105    |
| Total Potential Net Income                                                                       |       |          |             | \$106,089   |
|                                                                                                  |       |          |             |             |
|                                                                                                  |       |          |             |             |

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 VALUE ENGINEERING COMMENTS
 

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**Comment No. 9 Placement of material from Sta 5+250 to 25+000 in the near shore disposal areas:**

The material from this reach is scheduled to be placed in confined upland disposal sites along the Savannah River. This is the most economical way for disposal. With upland sites being depleted, consideration should be given to the option of utilizing the near shore disposal areas. Current cost of upland use is say \$4.00/cy and to put it in the near shore areas is say \$6.50/cy. There are additional costs associated with upland placement such as dike maintenance while there is none associated with the near shore sites. Consideration should be closely monitored or even be offered as option bid items in future contracts to see if this will offset any anticipated disposal utilization fees.

**Comment No. 10 Allow clamshell dredging in all dredging areas of this project outside the naturally enriched Cadmium zones and offshore disposal (for dredging during fish window):**

By making clamshell dredging available to the contractor in all areas of the project outside the zone containing naturally enriched Cadmium, the project would potentially benefit by being able to operate during the fish window. Being able to operate during the fish window would reduce the number of mobilizations and demobilizations required by the contractor. Depending on production rates between the different available dredging techniques, clamshell dredging may reduce the project costs and the overall construction duration.

**Comment No. 11 Use Military personnel labor for cleaning/clearing Bear Creek:**

The environment around Bear Creek is very remote and difficult to access using heavy construction equipment. Removal of fallen trees and snags from this area which are blocking freshwater flows will be a difficult and labor intensive task. In the past, there have been occasions when the military has taken it upon itself to accept the challenge of such a Civil Works project and use it as a training project. Although, at the present time, are armed forces are taxed by lengthy deployments, this could be considered a training opportunity if the manpower is available and willing at the time the project is constructed.

**Comment No. 12 Utilize Amphibian Pontoon Tracked Excavators for clearing Bear Creek:**

This equipment has been demonstrated in the Charleston District as the most efficient and economical method for clearing and snagging of highly dense vegetation from shallow, swampy nearly undefined channels. This equipment is currently being used to clean out an old, almost nearly undefined channel of old hurricane debris which has devastated the Pocatigo Swamp. The equipment can operate without the aid of mats and can remove and lift very large cypress trees out of the way. The equipment can completely float so will not require barging as long as the boom can reach the bottom. The machine will have to make its path wide enough to get through the area a minimum of 18 feet. (width of machine). The purpose of the Pocatigo Project was to open out old channels to obtain previous natural flows and to also allow access to areas where small boats could perform aquatic weed spraying and the replanting of cypress trees which had fallen during the hurricane. Production rates for this equipment varies depending on density of debris but has averaged over 100 feet per hour in fairly dense swampy remote conditions at a cost of around \$350/hr. Costs are only \$275/hr if it can be accessed by land and is not remote.

**Comment No. 13 Verify costs for removing the CSS Georgia:** The costs for performing the removal and preservation requirements were provided by Judy Wood (SAM-PD-EI) and should be investigated to insure that reasonable costs and procedures are used. There is potential for VE savings on the performance of this project task but will require a specialized team familiar with archeological salvage and preservation coupled with innovative marine engineers to reasonable identify potentials.

**Comment No. 14 Verify costs for performing the removal of debris:** The costs for performing the removal of debris were provided by others based on old historical construction techniques, quantities and costs from the last deepening project. There is potential for VE savings on the performance of this project task. Investigations should be made to insure that efficient construction techniques will be used to fully capture any potential cost savings.

**Comment No. 15 Allow dredging by clamshell during fish windows outside the naturally enriched Cadmium zones and offshore disposal (for dredging during fish window):** By making clamshell dredging available to the contractor in all areas of the project outside the zone containing naturally enriched Cadmium, the project would potentially benefit by being able to operate during the fish window. Being able to operate during the fish window would reduce the number of mobilizations and demobilizations required by the contractor. Depending on production rates between the different available dredging techniques, clamshell dredging may reduce the project costs and the overall construction duration.

**Comment No.16 Consider requesting that fish windows are extended or lifted:** There are many mobilization and demobilization costs included in the estimate. This is partly due to the starting and stopping of work because of the fish windows and this increases the cost significantly. If the fish windows could be lifted or the work period extended some of the costs may be reduced, since this would reduce the stoppages and allow for more work time.

**Comment No. 17 Lower elevation of the DO system to reduce added hydraulic related costs:** By lowering the submerged portion of the dissolved oxygen system within the water column, the project could take advantage of the head/pressure differences to reduce the amount of energy required to pump the oxygen saturated water back into the river.

**Comment No. 18 Verify required buffer zone width for the DO system at Mulberry Grove:** The plan shows that a buffer zone of 100 feet be maintained between the river and the Speece Cone OD equipment. This buffer zone adds a great deal of cost to the project and could be alleviated if reduced or eliminated entirely. Criteria should be investigated to check validity since there are similar commercial and industrial plants already in the nearby area that produce similar impacts and are allowed without buffers.

**Comment No. 19 Determine if the number of pipes can be reduced between the DO systems and the river by utilizing larger diameter pipes or conduits to combine inlets and outlets:** The current design uses separate inlet and outlet 20" diameter ductile iron pipes running from each of the Speece Cone OD units to the water source. Investigations should be made to verify that a more cost effective system could be designed when there are several of these units

being constructed in close proximity to each other. It is believed that at a minimum, the intake portion could be redesigned to take advantage of using less but larger intake pipes.

**Comment No. 20 Use available sand materials from the Tide Gate abutments to fill Geo-tubes, Containers or Bags:** Materials removed from the abutments provide for a great source which could be used for filling Geo-textile containment products. Also noted in this area is the large quantity of rip rap that will be removed. This quantity of rip rap should be considered as valuable salvage and used for other aspects of this project.

**Comment No. 21 Allow the use of Geo-bags to build plugs and diversion structures throughout the project where Geo-tubes or rock is used:** Geo-bags could be used in-lieu of Geo-tubes should the installation of the tubes become prohibitive. The cost for the smaller containments of 10 cubic yards will cost say \$500 each as compared to 250 cubic yards in a tube at \$2500 each. \$50/CY vs. \$10/CY. This is still a tremendous savings over rip rap which is pricing out around \$200/cy due to the high cost of trucking from distant quarry locations. This is assuming the fill for the Geo-textile products are free and readily available nearby. Also noted that the design slopes of 3 to 1 have the potential of being steepened to 2.5 to say 1.5 to 1 if constructed effectively thereby reducing the preliminary estimated quantities for all these materials being ultimately used in the project.

**Comment No. 22 Allow the dredged materials from upstream mitigation areas to be used to build up the USFWS dikes:** The project plan is to dredge 463,000 C.Y. of material from freshwater areas upstream of the project to increase freshwater flows into the Savannah National Wildlife Refuge. Presently the assumption is that the material will be pumped into scows, carried downstream to the harbor disposal areas, and pumped out of the scows. This is an excessively costly method of disposal. The existing dikes within the refuge are in bad conditions in many locations. If the Fish and Wildlife Service agrees, the material from these creeks could be used to help rebuild their dikes while reducing disposal costs. Due to the sensitive nature of the refuge, the full concurrence of the Fish and Wildlife Service would be required. Also, it is likely that additional testing of the material would be required during the engineering phase of the contract to establish the gradation of the material as well as the possible presence of contaminants.

**Comment No. 23 Consider as part of the mitigation, pumping the dredged material to the underside of the marsh mat:** The marshes within the wildlife refuge and the adjacent areas are decreasing in elevation due to the combined effect of subsidence and sea level rise. Although it is a novel idea, one possible way to offset this decrease would to pump the dredged material below the marsh mat in these areas. Once again, extensive coordination with the resource agencies would be required as well as material testing. However, this method could potentially provide both an environmental benefit as well as a cost savings to the project.

**Comment No.24 Consider reducing the width of the outer bar channel from 600 feet to 500 feet:** The present channel bottom design is 600 feet wide. If the channel bottom width is reduced to 500 feet, the amount of dredge material in both the channel bottom and side slopes, and the time for the work should be reduced. The Environmental agencies may find this agreeable and there should be negligible effect on shipping.

**Comment No. 25 Consider deepening only 500 feet wide in lieu of 600 feet wide bottom in the outer bar channel using a step arrangement:** The present design is a 600 foot wide channel bottom on the outer bar. A 500 foot wide channel bottom with a 100 foot step should be considered. This would provide for less dredge material to be disposed and also provide some advanced maintenance. The 100 foot step would trap material sloughing from the side slope thus providing the advance maintenance feature. The reduction in channel width should have negligible effect on shipping.



## **APPENDIX A:**

## **CONTACT DIRECTORY**

VALUE ENGINEERING STUDY ATTENDEE SHEET SIGN-IN SHEET  
May 20-22, 2008

PROJECT DESCRIPTION: VES 08-21 Expansion of Savannah Harbor  
P2 113006

TIME: 0830

PLACE: Savannah, Georgia (Hilton Desoto Madison Conference Room)

| NAME:             | POSITION:                        | ORGANIZATION                                | Email address and Telephone:                                                                 |
|-------------------|----------------------------------|---------------------------------------------|----------------------------------------------------------------------------------------------|
| Tommy Blewett     | Facilitator/ Team Leader         | John T. Blewett, PE<br>Consulting Engineers | <a href="mailto:jtbcc@alltel.net">jtbcc@alltel.net</a>                                       |
|                   |                                  |                                             | 912-754-7445                                                                                 |
| Tom Child         | Geo-tech                         | SAW                                         | <a href="mailto:Thomas.child@usace.army.mil">Thomas.child@usace.army.mil</a>                 |
|                   |                                  |                                             | 910-251-4708                                                                                 |
| Brian Williams    | Geo-tech/<br>Marine Construction | SAC                                         | <a href="mailto:Brian.p.williams@usace.army.mil">Brian.p.williams@usace.army.mil</a>         |
|                   |                                  |                                             | 912-652-5188                                                                                 |
| Jim Henderson     | Dredging/Cost Engineer           | SAC                                         | <a href="mailto:James.e.henderson.jr@usace.army.mil">James.e.henderson.jr@usace.army.mil</a> |
|                   |                                  |                                             | 843-329-8141                                                                                 |
| David Griffin     | Civil/ Structures                | GA DOT                                      | <a href="mailto:dagriffin@dot.ga.gov">dagriffin@dot.ga.gov</a>                               |
|                   |                                  |                                             | 404-631-1228                                                                                 |
| Carol Abercrombie | Coastal Engineer                 | SAS                                         | <a href="mailto:Carol.h.abercrombie@usace.army.mil">Carol.h.abercrombie@usace.army.mil</a>   |
|                   |                                  |                                             | 912-652-5514                                                                                 |
| Alan Garrett      | Project Manager                  | SAS                                         | <a href="mailto:Thomas.A.Garrett@usace.army.mil">Thomas.A.Garrett@usace.army.mil</a>         |
|                   |                                  |                                             | 912-652-5172                                                                                 |
| Hope Moorer       | Program Manager                  | GPS (Georgia Ports Authority)               | <a href="mailto:hmoorer@gaports.com">hmoorer@gaports.com</a>                                 |
|                   |                                  |                                             | 912-964-3883                                                                                 |
| Joe Hoke          | Hydraulic Engineer               | USACE SAW/SAS                               | <a href="mailto:Joseph.t.hoke@usace.army.mil">Joseph.t.hoke@usace.army.mil</a>               |
|                   |                                  |                                             | 912-652-5516                                                                                 |
| Joe Hudak         | Civil Engineer                   | USACE                                       | <a href="mailto:Joseph.d.hudak@usace.army.mil">Joseph.d.hudak@usace.army.mil</a>             |
|                   |                                  |                                             | 912-6652-5681                                                                                |
| Jamie Measmer     | Electrical Engineer              | USACE                                       | <a href="mailto:Jamie.d.measmer@usace.army.mil">Jamie.d.measmer@usace.army.mil</a>           |
|                   |                                  |                                             |                                                                                              |

|                     |                 |               |                                                                                          |
|---------------------|-----------------|---------------|------------------------------------------------------------------------------------------|
| Craig N. Wiederhold | Plan Formulator | USACE SAM/SAS | <a href="mailto:Craig.n.wiederhold@usace.army.mil">Craig.n.wiederhold@usace.army.mil</a> |
|                     |                 |               | 912-484-8283                                                                             |
| Larry Keegan        | PM for GPA      | CH2M Hill     | <a href="mailto:Larry.keegan@ch2mhill.com">Larry.keegan@ch2mhill.com</a>                 |
|                     |                 |               | 912-330-3025                                                                             |
| Wilbur Wiggins      | Civil Engineer  | USACE         | <a href="mailto:Wilbur.k.wiggins@usace.army.mil">Wilbur.k.wiggins@usace.army.mil</a>     |
|                     |                 |               | 912-652-5542                                                                             |
|                     |                 |               |                                                                                          |
|                     |                 |               |                                                                                          |

## **APPENDIX B:**

## **SPECULATION LIST**

|                                |                         | <b>SPECULATION LIST</b>                                                                                                                                              |
|--------------------------------|-------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Y,<br/>N,<br/>C,<br/>BD</b> | <b>Proposal<br/>No.</b> | <b>PROPOSALS</b>                                                                                                                                                     |
| <b>Y</b>                       | <b>1</b>                | Consider all cut-off structures/Core to be made out of Geo-tube with a layer of rock over                                                                            |
| <b>Y</b>                       | <b>2</b>                | Make all cut-off using rock filled gabions in lieu of rock                                                                                                           |
| <b>Y</b>                       | <b>3</b>                | Re-use concrete from Tide Gate for core of sediment basin sill                                                                                                       |
| <b>Y</b>                       | <b>4</b>                | Use sheet pile in lieu of rock at McCoy cut for diversion structure                                                                                                  |
| <b>Y</b>                       | <b>5</b>                | Re-claim rock from New Cut area, above mean high water, for closure structures                                                                                       |
| <b>Y</b>                       | <b>6</b>                | Use sand from the southern part of 2A for sand fill at Rifle Cut plug                                                                                                |
| <b>Y</b>                       | <b>7</b>                | Use precast concrete and "H" piles for closure structures at McCoy Cut diversion structure                                                                           |
| <b>Y</b>                       | <b>8</b>                | Install piping between DO system and river using tunnels to prevent cutting down or disturbing the ground cover.                                                     |
| <b>C</b>                       | <b>9</b>                | Placement of material from station 5+250 to 25+000 in the near shore disposal areas                                                                                  |
| <b>C</b>                       | <b>10</b>               | Allow clamshell dredging in all dredging areas of this project outside the naturally enriched Cadmium zones and off shore disposal (for dredging during fish window) |
| <b>C</b>                       | <b>11</b>               | Use Military personnel labor for cleaning/clearing Bear Creek                                                                                                        |
| <b>C</b>                       | <b>12</b>               | Utilize pontoon track vehicle for clearing Bear Creek                                                                                                                |
| <b>C</b>                       | <b>13</b>               | Verify that the cost in the estimate for removing the CSS Georgia is correctly identified (shows correct cost)                                                       |
| <b>C</b>                       | <b>14</b>               | Verify the cost in the estimate for removal of debris is correct                                                                                                     |

|   |    |                                                                                                                                                               |
|---|----|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| C | 15 | Allow dredging by clam shell during fish windows outside the naturally enriched Cadmium zones and off shore disposal (for dredging during fish window)        |
| C | 16 | Consider requesting that fish windows are extended or lifted                                                                                                  |
| C | 17 | Lower elevation of the DO system to reduce added hydraulic related costs                                                                                      |
| C | 18 | Verify required buffer zone width for DO system                                                                                                               |
| C | 19 | Determine if the number of pipes between the DO system (generators) and the river by combining inlet and/or outfalls and be reduced                           |
| C | 20 | Use available sand materials from Tide Gate abutments to fill Geo-tubes                                                                                       |
| C | 21 | Allow the use of Geo-bags to build plugs in lieu of Geo-tubes                                                                                                 |
| C | 22 | Allow the dredge materials from upstream mitigation areas to be used to build up the USFWS dikes                                                              |
| C | 23 | Consider as part of the mitigation, pumping the dredge material to the underside of the marsh mat                                                             |
| C | 24 | Consider reducing the width of the outer bar channel from 600' to 500' in width                                                                               |
| C | 25 | Consider deepening only 500' wide in lieu of 600' wide bottom in outer bar channel using a step arrangement                                                   |
| N | 26 | Use alternate disposal site for McCoy cut dredging, McCoy Cut, Little Back River, Middle River                                                                |
| N | 27 | Replace steel sheet pile with vinyl sheet pile                                                                                                                |
| N | 28 | Use clamshell to remove the debris and dispose off shore                                                                                                      |
| N | 29 | Put Cadmium in Steel drums and ship to China                                                                                                                  |
| N | 30 | In developing the contract consider allowing Clam Shell outside the naturally enriched Cadmium zones and off shore disposal (for dredging during fish window) |
| N | 31 | Remove Tide Gates but leave in place the abutments and not widen the channel in this area                                                                     |

An AREVA and Siemens Company

**NEW SAVANNAH BLUFF  
LOCK AND DAM  
PROJECT SAVANNAH RIVER  
GEORGIA AND SOUTH CAROLINA  
FISH PASSAGE FACILITY  
ENGINEERING REPORT**

**Prepared for:  
U.S. ARMY CORPS OF ENGINEERS**



**Prepared by:  
FRAMATOME ANP DE&S, INC.**

**December 2002**



**A  
FRAMATOME ANP  
FRAMATOME ANP DE&S**


**FRAMATOME ANP**

An AREVA and Siemens Company

**FRAMATOME ANP DE&S**

December 16, 2002

HV02170

 Attention: Mr. William Lynch  
CESAS-PM-C

 US Army Corps of Engineers - Savannah District  
100 West Oglethorpe Ave.  
Savannah, GA 31041

 Re: New Savannah Bluff Lock & Dam Fish Bypass System  
Engineer Report 35 Percent Design - Final Submittal  
Purchase Order No. DACW01-00-D-0019

Dear Mr. Lynch:

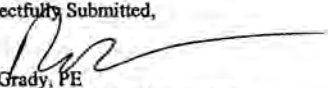
As discussed during our meeting on December 4, 2002 with the City of Augusta, enclosed please find:

- Thirty (30) hard copies of the Final Engineering Report complete with text, drawings & figures, and
- A compact disc with the subject report in pdf format and drawings SAVANNAH 1 THRU SAVANNAH 6 and Boring Drawings Plate C4-1 & C4-2 in dgn format.

Please note per copy of this letter, I am also forwarding two (2) hard copies of the report and an identical compact disc to Mr. Maurice James, USACE Mobile District. It has been a pleasure to work with the U.S Army Corps of Engineers on this project and we look forward to future opportunities.

Please let me know if you have any questions or need additional information.

Respectfully Submitted,

  
 Ron Grady, PE  
 Hydropower & Natural Resources

Attachments

 Cc w/Attachments: Mr. Maurice James (Two Copies)  
Mr. Steve Arnold (Two Copies)  
Mr. Jon Truebe (One Copy)  
Project File (One Copy)

**FRAMATOME ANP DE&S**

 P.O. Box 37916 Charlotte, NC 28237-7916  
 Tel: 704-805-2000 Fax: 704-805-2800



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## **I Introduction**

### **A. Study Authority**

This report has been prepared by Framatome ANP DE&S, together with its subcontractor Lakeside Engineering, Inc. This engineering report contains the results of a study undertaken to assess the technical feasibility of a fish bypass system and to complete project design to a level of approximately 35 percent. The "Terms of Reference" for this design effort was issued by the U.S Army Corps of Engineers (USACE). The authorization to begin work was issued September 9, 2002 via Purchase Order DACW01-00-D-0019.

### **B. Study Objectives**

#### **Background Information**

Task order (DACW01-00-D-0019) was issued for **Phase II** of the feasibility study to develop the fish passage element of the New Savannah Bluff Lock & Dam Repair and Rehabilitation Project.

In general, this complete effort was divided into two phases. **Phase I** (Completed on July 19, 2002) included a review of project design activities to date (Section 216 Disposition Study), identification of alternative fishway configurations, preliminary screening and ranking of the alternatives. Conceptual designs of the most promising fishway alternatives were developed to accommodate a rough order of magnitude (ROM) cost estimate of each alternative that passed the initial evaluation. Consultation with appropriate Federal and State regulatory agencies, and selection of a recommended alternative were the final steps of **Phase I**.

**Phase II**, completed under this task order, includes feasibility level (30 to 35 percent) design of the selected rock ramp fishway alternative in sufficient detail to accommodate a MCACES based cost estimate and operation & maintenance costs. Design activities for the selected rock ramp fishway alternative are in general conformance with Engineering and Design for Civil Works Projects (USACE, ER 1110-2-1150) as directed by the Contracting Officer's Representative (COR) with consultation from the Savannah and Mobile Districts USACE project staffs.

#### **Overall Project Objectives**

Listed below are the overall project objectives.

- Provide engineering data (including quantities for excavation, fill and construction materials) and analysis sufficient to develop a feasibility level project schedule (by others) and cost estimate (by others).
- Assist the USACE Project Delivery Team (PDT) in the development of a complete project schedule and schedule of funds needed for final design and construction.
- Develop a preliminary design of the recommended plan to the level required to ensure that the design can be implemented without the need for major revisions and that the baseline cost estimate is adequate.

- Determine the relative engineering requirements for various structural and nonstructural elements.
- Develop design studies and operational plan requirements.
- Establish and describe the basic configuration of all structural elements including plan, profiles and basic project details to a feasibility level.
- Provide sufficient information to establish real estate requirements.
- Identify borrow and disposal requirements, easements and right-of-ways for the proper disposal of dredged or excavated material.
- Generate a detailed engineering appendix for the feasibility report complete with drawings, attachments, etc.
- Develop baseline project performance requirements

### **Feasibility Design Development**

In accordance with the above stated objectives, this feasibility level design (30 - 35 percent) effort was performed for the USACE selected rock ramp fish passage system at the New Savannah Bluff Lock and Dam (NSBL&D). This design effort was executed in accordance with the following five (5) primary tasks:

- Task 1 Preferred Project Layout & Report Outline** - Perform studies and engineering analysis to establish the preferred project layout, including plans, profiles and basic details of the rock ramp fish passage configuration and appurtenant structures. This effort shall include identification, design and description of any modifications of the existing structure to ensure the performance of the fish passage. Design of any modifications to the existing structure will also be carried to the feasibility (35%) level.
- Task 2 Submit General Arrangement Drawings and Report Outline** - Submittal of Preliminary General Arrangements Drawings and Feasibility Report Annotated Outline to USACE for review and comment.
- Task 3 Draft Engineering Appendix for Feasibility Design Report and Detailed Layout Drawings** – Complete feasibility level design and generate a draft engineering appendix complete with project drawings in sufficient detail to support the development of reliable project schedules and baseline cost estimates with reasonable and acceptable accuracy. The engineering appendix and associated drawings will be submitted to the USACE for distribution to the Agencies for pre-meeting review. It is also anticipated that the USACE will utilize this submittal to facilitate any necessary internal technical reviews by the Project Delivery Team (PDT) and an Independent Technical Review (ITR) board.
- Task 4 Agency Consultation/USACE Internal Review Meetings** - Participate in a one day Agency consultation meeting with the USACE to present and seek Agency consensus for the final project configuration. As part of the Agency coordination, the A-E may be required to participate in a review meeting as requested by the COR. This meeting will be held at the same location as the Inter-Agency meeting.

**Task 5 Document Revisions and Final Report Submittal** - The engineering appendix for the feasibility report and associated drawings will be revised as directed by the COR to reflect agency comments and recommendations emanating from the USACE internal technical review process. Post document revisions, a final report will be submitted.

### C. Project Overview

The New Savannah Bluff Lock and Dam (NSBL&D) is located along the Savannah River, at River Mile 187.4, approximately 13 river miles downstream from the City of Augusta in Richmond County, Georgia and the City of North Augusta in Aiken County, South Carolina. The project constitutes the first and most downstream lock and dam facility along the Savannah River. The following facilities are located upstream of the NSBL&D (Refer to Figure No 1):

| Facility                  | River Mile |
|---------------------------|------------|
| Augusta City Lock & Dam   | 207.2      |
| Stevens Creek Dam         | 208.1      |
| J. Strom Thurmond Project | 220.9      |

The NSBL&D facility was constructed by the U.S. Army Corps of Engineers and consists of a lock chamber, dam, operations building, and a 50-acre park/recreation area. Construction of the Project was completed in 1937. The dam structure is 360 feet long and contains five vertical spillway gates. Each gate bay is 60 feet long and located between concrete piers. The gates on each end of the dam spillway are overflow type and measure 12 feet tall. The three middle spillway gates are 15 feet tall and are non-overflow type. All of the spillway gates are remotely operated from the J. Strom Thurmond Hydroelectric Facility located upstream. The lock is located along the right abutment (Georgia Side) and measures approximately 56 feet wide and 360 feet long, with a maximum lift height of approximately 15 feet.

Presently, the facility provides ponding upstream to support several water intakes and recreation. While commercial traffic no longer passes through the Project lock, some small recreation vessel locking is provided. The facility provides little in the way of flow retention or river regulation.

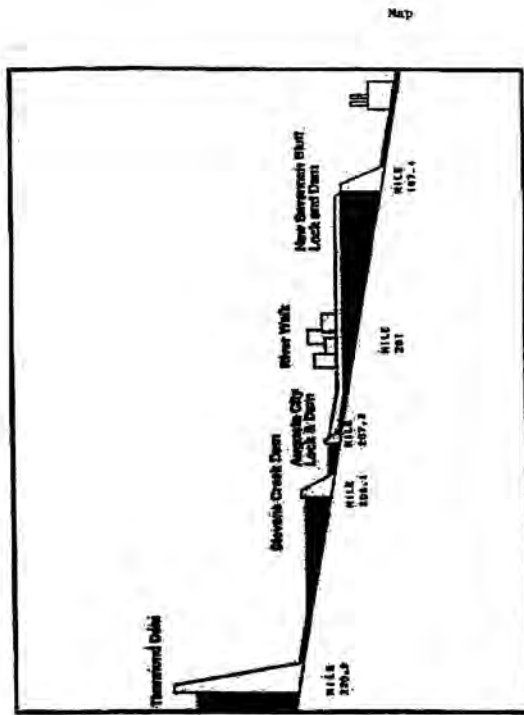


FIGURE 1. SAVANNAH RIVER PROFILE IN THE VICINITY OF THE NEW SAVANNAH BLUFF LOCK & DAM.

#### **D. Project Ownership**

This project was constructed by the U.S. Army Corps of Engineers, Savannah District, and is owned by the Federal Government. In response to recent Congressional direction (see Section II B), the USACE has been instructed to fully repair the lock and dam and provide fish passage, and to subsequently transfer ownership of the Project to the City of North Augusta and Aiken County, South Carolina.

#### **E. Authorized Project Purpose**

The NSBL&D project was authorized for the sole purpose of improving the commercial navigation channel between the upper limits of the Savannah Harbor and the head of navigation at Augusta, Georgia. It was a modification to the existing Savannah River below Augusta (SRBA) navigation project.

#### **F. Authorized Project Uses**

This project improved the commercial navigation channel for the SRBA project by way of its lock facilities and provided a 9-foot navigation channel between the upper limits of the Savannah Harbor and the head of navigation at Augusta, Georgia.

The project has not served commercial navigation since 1979 and no longer regulates downstream flows for navigation. In 1987, the public park and recreation facility and the lock were leased to the City of Augusta *"for purposes of operation and maintenance of the Project"*.

Although the Savannah District no longer operates the lock, it continues to operate the vertical lift gates of the dam to manage pool elevations for incidental uses such as water supply and water-related recreation. The vertical lift gates are remotely operated 6 to 18 times a week during normal conditions to control the elevation of the pool.

The Savannah District also operates this project in conjunction with the J. Strom Thurmond project to pass some migrating anadromous fish species. Large releases, of 16,000 cfs, are made from the J. Strom Thurmond project usually during the first week of May, but only if there is excess water in the J. Strom Thurmond reservoir that must be released. This enables some migrating anadromous fish species to pass under the vertical lift gates and over the sill of the NSBL&D. During drought years, this operation usually cannot be conducted. During normal to high flow years, it generally is conducted.

Augusta-Richmond County operates the lock to pass migrating fish species, as required, under an existing lease agreement. Between 30 and 50 lock cycles are performed annually during the period of March 15 and June 15 for the purpose of fish passage. They also operate the lock between 50 to 100 cycles per year for recreational boating traffic.

On December 8, 1998, the Secretary of the Army and Richmond County, Georgia, mutually agreed to amend the existing lease agreement so that:

*"Richmond County acting by and through the Mayor of the Augusta-Richmond County Commission is responsible for all operation and maintenance costs of this lock and public park premises until 7 December 2008 and thereafter for so long as the project remains in operation"*



## **II Previous Studies**

### **A. Section 216 Disposition Study, September 8, 2000**

The purpose of this study was to review the current uses of the NSBL&D Project, Savannah River, Georgia and South Carolina, and recommend its future disposition. In 1979, the last commercial shipment passed through the NSBL&D project and, consequently, maintenance of the navigation channel was discontinued. Funding for proper maintenance of the lock and dam was curtailed. The current condition of the project is poor. Major repairs and rehabilitation are required to assure a safe and reliable project. The total cost to conduct necessary and immediate repairs and rehabilitation was estimated at \$6,800,000.

Although the project no longer serves commercial navigation, the study determined that the project currently serves water supply users including one municipality, five industries, and one sod farm; water-related recreation opportunities such as general boating and fishing and specialized rowing and powerboat race events; and regional economic development and tourism. It is also operated to pass some migratory anadromous fish species.

During the 216 study period, the Savannah District contacted state and local interests to determine if they were interested in taking over ownership of the project. No entity was interested in taking it over in its present condition. However, in recognition of the significant benefits the project provides to the surrounding area, local interests indicated they would consider accepting ownership if the Federal Government pays for all immediate and necessary repairs and rehabilitation.

This study considered and evaluated four alternatives:

1. Status quo
2. Transfer ownership
3. Reauthorization
4. De-authorization

The report also included a letter proposal by the City of North Augusta and Aiken County, South Carolina, which stipulated their terms for transfer of ownership or reauthorization of this project.

As of the study completion date, a non-Federal entity willing to cost-share immediate repairs and rehabilitation, and pay for all future repairs and rehabilitation of the project had not been identified. Accordingly, the District had no other option but to proceed with a recommendation to Congress for complete removal of the structure at full Federal cost estimated at \$5,350,000 and de-authorization of this feature of the SRBA navigation project.

## **B. Section 216 Disposition Study, July 2001 Addendum**

The purpose of this addendum was to respond to Congressional direction in Section 348(l) of the Water Resources Development Act (WRDA) of 2000, P.L. 106-541, and the Omnibus Appropriations Act, 2001, P.L. 106-554. As a result of the WRDA 2000, Congress has authorized the Savannah District, USACE, to repair and rehabilitate the Project at full Federal cost, provide fish passage, and to subsequently transfer the Project to the City of North Augusta and Aiken County, South Carolina.

During comments on the draft of this addendum, fishery resource agencies indicated they had concern with the fishway design in the original September 8, 2000 216 Study Report. They recommended a full review of fish passage options in collaboration with fishery resource agencies, and if modifications to the original 216 Study fishway design are proposed they will be coordinated with Federal and State fishery resource agencies.

## **C. New Savannah Bluff Lock and Dam Project, Savannah River Georgia and South Carolina, Fish Passage Report, August 2002.**

### **C.1 Objectives of Study**

The basic objectives of this study (Phase I) were to review previous study efforts, identify alternative fish passage configurations, coordinate with various fishery resource agencies to solicit design input, and foster cooperation. Following this information gathering phase, study objectives were to screen and rank the various fish passage alternatives, and select two or three for development to sufficient detail for a rough order of magnitude cost estimate. This first level of fish passage alternative screening was performed in consultation with resource agencies at a meeting held on May 21, 2002. A second round of consultation and review by concerned resource agencies took place during a meeting held on June 26, 2002. The objective of this meeting was to present study conclusions, and to receive resource agency recommendations for the best fishway design alternative to carry forward to the 35 percent design level (Phase II). Additional work scope details, objectives, and consultation meeting minutes are provided in the Phase I report (FANP DE&S 2002).

### **C.2 Study Methods**

Methods employed during the Phase I study were a historical information review, development of contemporary topographic, hydrographic, and subsurface geology data, resource agency consultation including confirmation of design criteria, and a site-specific analysis of fish passage alternatives. Fishway alternatives reviewed included:

- Pool & Weir/Gabion
- Full River Rock Ramp
- European/Natural Channel
- Rock Ramp Gate No. 5
- Rock Ramp Horseshoe SC Side
- Denil Fish Ladder

- Pool & Weir Fish Ladder
- Vertical Slot Fish Ladder
- Fish Passage Via Navigation Lock
- Fish Lock & Lift
- Fish Pump

### C.3 Results and Conclusions

A summary matrix of fishway design alternatives considered, are shown in Table 1. The matrix lists the various types of fishway designs considered, down the left side, and many of the important design criteria across the top. This matrix was reviewed with resource agency personnel at the June 26, 2002 consultation meeting held in Savannah, Georgia. The purpose of the meeting was to review the draft (Phase I) report and make recommendations for the preferred design to carry forward to the 35 percent design level.

One of the most important fishway selection criteria for the NSBL&D site is how much operation and maintenance labor would be required to keep the fishway functional. The design options utilizing the existing navigation lock (Table 1, Alternative No. 5.5), individually designed and constructed fish lock or fish lift designs (Alternative No. 5.6), and a fish pump (Alternative No. 5.7), all have relatively high operation and maintenance costs associated with them. All of these designs require some type of mechanical/motorized equipment that must be maintained. These designs also require relatively high labor to operate and monitor performance. Although these designs have proven to be very effective at moving fish with diverse hydraulic requirements at other sites, the high level of operation and maintenance costs preclude them from further consideration.

As discussed in the resource agency communications (B. Rizzo October 25, 2000 memorandum, comments on September 8, 2000, 216 Amendment), the Gabion Pool and Weir design was not well received by resource agency personnel. Concerns were expressed over the hydraulics, stability, and aesthetics of this fishway design. Construction and operation and maintenance labor were also a concern. For these reasons, this design was dropped from further consideration.

The European/Nature-Like Channel design was given serious consideration. However, the space requirements would necessitate additional land purchase (complicated by an unwilling landowner). Additionally, channel stability issues, and operation and maintenance costs precluded this design.

The full river rock ramp shares many of the advantages of the smaller rock ramp designs considered (see below). However, the full river rock ramp requires the complete removal of all five dam gates and supporting structures. This is not an acceptable design because Congressional Project authorization requires the maintenance of the lock and dam structure. Also, the loss of river gated control of pool elevations at the site, and structural issues associated with demolition of the spillway structures, further detract from this alternative.

This process of elimination leaves two basic designs viable for consideration, the smaller rock ramps (either the Gate 5 or the horseshoe – South Carolina shore) and the standard structural swim-through fish ladder designs. These two designs were examined closely. The structural swim-through fish ladders have several baffle designs. However, for the species under consideration, the vertical slot baffle fish ladder is preferred, especially for American shad. Two variations of the small rock ramp are also under consideration, the Gate 5 rock ramp, and the S.C. horseshoe rock ramp.

The rock ramp designs have several advantages over the vertical slot fishway. The rock ramps have a broad range of hydraulic conditions that should accommodate many, if not all of the design target species. Rock ramps will also function well for downstream passage, are not capacity limited (number of fish), and will generally have lower operation and maintenance costs than a vertical slot fishway.

Among the two rock ramp designs, the horseshoe design, avoids dam structural concerns at Gate 5, in-river construction concerns and associated significant construction costs, and offers entrance/exit locations at the dam face for better upstream and downstream fish attraction. Therefore, the horseshoe rock ramp design on the South Carolina shore was selected by the USACE as best suited to the NSBL&D site and will be carried forward to the 35 percent design level.

TABLE 1  
SUMMARY OF FISHWAY DESIGN ALTERNATIVES  
(DEVELOPED IN PHASE I STUDY)

| Type                                                           | Phase I Report Reference | Agency Acceptance | Entrance Attraction Flow (cfs) | Transport Water (cfs) | Headpond Fluctuation Tolerances | Pass Design Species | Possible Cause of Fish Injury | Capacity (hour) | Continuity of Passage | No. of Pools | Maintenance/Dependability | Operating Personnel (hr) | Construction Difficulty | Spillway/Dam Loss (ln. ft.) | Add to Downstream Sturgeon Passage | Notes - Alternatives Evaluation                                                                                              |
|----------------------------------------------------------------|--------------------------|-------------------|--------------------------------|-----------------------|---------------------------------|---------------------|-------------------------------|-----------------|-----------------------|--------------|---------------------------|--------------------------|-------------------------|-----------------------------|------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| Pool & Weir/Gabion                                             | 5.1                      | no                | 600                            | 200                   | low                             | moor                | fallback                      | medium          | yes                   | 17           | low/high                  | Low-medium               | high                    | 0                           | fair                               | Eliminated-Construction difficulty, low headpond fluctuation tolerance, supplemental attraction flow                         |
| Full River Rock Ramp                                           | 5.2                      | yes               | full river                     | full river            | medium                          | yes                 |                               | unlimited       | yes                   | 17+          | low/high                  | low                      | high                    | 300                         | good                               | Eliminated - Loss of dam and pool control, Congressional authorization requires maintaining dam/lock structures              |
| European/Natural Channel                                       | 5.3                      | yes               | 600                            | 600                   | medium                          | yes                 |                               | high            | yes                   | 1            | medium/high               | low                      | high                    | 0                           | no                                 | Eliminated - requires root errata from unwilling landowner, channel stability/maintenance concerns                           |
| Rock Ramp Gate No. 5                                           | 5.4.1                    | yes               | 600                            | 600                   | medium                          | yes                 |                               | high            | yes                   | 23+          | medium/high               | low                      | medium                  | 60                          | no                                 | Preferred - may take rock adjustments after initial trials, difficult in-river construction, pool and dam stability concerns |
| Rock Ramp Horseshoe SC Side                                    | 5.4.2                    | yes               | 600                            | 600                   | medium                          | yes                 |                               | high            | yes                   | 23+          | medium/high               | low                      | medium                  | 0                           | good                               | Preferred - may take rock adjustments after initial trials, no forriver construction.                                        |
| Swim Through Fish Ladder - Dettl                               | 5.4.3                    | no                | 150                            | 25                    | 3 ft                            | no                  | fallback                      | medium          | yes                   | 1            | low/high                  | medium                   | medium                  | 0                           | no                                 | Eliminated - won't pass sturgeon and other design species                                                                    |
| Swim Through Fish Ladder - Pool & Weir                         | 5.4.3                    | possible          | 150-600                        | 60                    | low                             | moor                | fallback                      | 15,000          | yes                   | 22           | medium/high               | medium                   | medium                  | 0                           | fair                               | Eliminated - headwater sensitive, may not pass all design species                                                            |
| Swim Through Fish Ladder - Vertical Slot                       | 5.4.3                    | yes               | 600                            | 60                    | moderate                        | moor                | fallback                      | 15,000          | yes                   | 22           | medium/high               | medium                   | medium                  | 0                           | good                               | Preferred - third choice after two rock weir designs, may have effectiveness problems for some target species, higher O&M    |
| Fish Lock Using Navigation Lock (only as an emergency back-up) | 5.5                      | no                |                                |                       |                                 |                     |                               |                 |                       |              |                           |                          |                         |                             |                                    | Eliminated - Not suitable as primary passage device - high operation labor - Excellent emergency back up fishway.            |
| Mechanically Generated Currents                                | 5.5.1                    | no                | Mechanical flow inducer        | One lock cycle        | high                            | yes                 |                               | unlimited       | no                    | 1            | medium/medium             | high                     | low                     | 0                           | fair                               | Eliminated - High operation labor requirements.                                                                              |
| Gravity Flow Gate Manipulation                                 | 5.5.2                    | no                | 150-600                        | 500                   | high                            | yes                 |                               | unlimited       | no                    | 1            | medium/medium             | high                     | low                     | 0                           | fair                               | Eliminated - High operation labor requirements and high O&M requirements.                                                    |
| Fish Lift/Fish Lock                                            | 5.6                      | yes               | 150-600                        | 60                    | high                            | yes                 | crowding                      | 15,000          | 10min/cycle           | 1            | high/medium               | high                     | high                    | 0                           | no                                 | Eliminated - High operation labor requirements and high O&M requirements.                                                    |
| Fish Pump                                                      | 5.7                      | no                | 150-600                        | 5                     | unlimited                       | moor                | holding in pipe               | 28,000          | yes                   | 0            | high/medium               | high                     | low                     | 0                           | no                                 | Eliminated - High operation labor requirements and high O&M requirements.                                                    |

### III Site Description

#### A. Project Site Description Relative to Fish Passage

The NSBL&D at River Mile 187.4 (Refer to Figure No. 1) is the lowest fish barrier on the Savannah River. The 7,508 square mile drainage area has an average river discharge at the site of approximately 9,500 cfs (1952 through 1998). The flows and water elevations, as listed in the USFWS October 25, 2000, Ben Rizzo design memorandum (Appendix G.1), are based on the 1952 through 1998 period of record. It is important to remember the period of record used in the USFWS analysis predates the construction of the Hartwell (1962) and Richard B. Russell (1982) Projects, two major flood control projects in the basin immediately upstream of the J. Strom Thurmond Project.

The normal headwater elevation at NSBL&D is 114.5 feet (NGVD). Headwater control is very good due to the five gates in the spillway that are operated in conjunction with the upstream reservoirs. The dam structure has two fixed crested overflow type gates, one on the Georgia side and one on the South Carolina side of the river, that are 60 feet wide with an overflow invert of 112.0 feet. The center of the dam structure has three 60 feet wide steel lift gates with an invert of 100.5 feet. The low normal tailwater elevation is 101.5 feet and extreme low tailwater is 98 feet. Consequently, a fishway design maximum head of 17.5 feet (which assumes a headwater elevation of 115.5), minimum headwater of 113.5 feet, and normal headwater of 114.5 feet (NGVD) were used for design purposes. The lock chamber is 56 feet wide and approximately 360 feet long. The riverside lock wall extends about 270 feet downstream and 330 feet upstream of the dam respectively.

#### B. Field Investigations

##### B.1 Subsurface

In support of this study, seven subsurface borings were conducted under the direction of the USACE along the east abutment (Appendix B, Plates C4-1 & C4-2). According to the boring logs, the material is predominately composed of silt and sand with some traces of mica. The borings were advanced to depths of 18 feet (boring B-14-02, most upstream boring) to 30 feet (boring B-02-02, most downstream boring). The water table varies from around elevation 110 (upstream) to elevation 99 downstream. No rock was encountered within any of the boreholes. Standard Penetration Tests were performed at about 1.5 foot intervals, with blow counts measured from a low of 2 to as high as 27. In general, the material density can be characterized as loose to medium.

From a constructability perspective, common excavation equipment may be utilized with no anticipated blasting. Some water control may be required. However, to eliminate most seepage infiltration, a sheet pile cutoff wall is installed at the upper headwater structure location, extending from the existing dam abutment cutoff wall in an easterly direction to a distance of approximately 30 feet beyond the headwater control structure.



## B.2 Fish Studies

Both Georgia DNR and South Carolina DNR have conducted management related studies of fish in the Savannah River near the NSBL&D Project site in recent years. Information from these studies were discussed during the May 21, 2002 consultation meeting, and helped to establish target species and seasonal passage windows. Clemson University has conducted the most recent fishery investigations at the project site in 2001 and 2002. These studies have focused on migratory species approaching the project dam. While these results are not yet published, valuable design information was gleaned from results to date including:

- Upstream fish passage efficiency was estimated for American shad as approximately 60 % in 2001, and less than 40 % in 2002 due to drought and low lock cycling frequencies;
- Observations indicate that fish travel up the Georgia shoreline when approaching the dam, and fish tend to congregate immediately downstream of Gate #5 along the S.C. shoreline.
- Successful radio tagging in 2002 should provide new data on the migration patterns of both shortnose sturgeon and robust redhorse in the near future.

## C. Hydraulic Conditions

The hydrology of the lower Savannah River has been substantially modified by the construction of several USACE multipurpose projects that include flood control capacity. These projects include the J. Strom Thurmond Project completed in 1954, the Hartwell Project completed in 1962, and the Richard B. Russell Project completed in 1984.

Headwater, tailwater, and daily discharge data were provided by the USACE for 1992 through April 2002. Percent exceedence curves were generated for each. The results are provided in Appendix E. While the data for the most recent 10-year period reflect current water management practices in the Savannah River basin, they also include several abnormal drought years. Therefore, the 1992 through 2002 period of record may underestimate future hydraulic conditions. The datum for the headwater gage is 100.58 feet (NGVD). The datum for the tailwater gage is 96.58 feet (NGVD). The normal headwater elevation at NSBL&D (50 percent exceedence) is about 114.5 feet, and normal tailwater elevation is about 100.5 feet. Normal head differential is about 14 feet, and maximum head is estimated at approximately 17.5 feet. The Project can control flows up to 20,000 cfs. Above this discharge, all five gates are pulled clear of the water. As river discharge increases, tailwater elevation rises and head decreases. At flows of 25,000 cfs, the head differential can reduce to as little as 6 inches.

Under low flow conditions, the project discharges a minimum downstream flow of 3,600 cfs, generally through gates 1 and 5 (overflow gates) with the remaining flow supplied through gates 2 through 4. Under extreme low flows, Project discharge may be altered, by adjusting gates 2 through 4, in order to meet the target minimum tailwater elevation of 98 feet. All Project gates are operated remotely from the J. Strom Thurmond Project. Under normal conditions, the crest of the two overflow gates remain fixed, and upstream generation flows

are passed by manipulation of gates 2 through 4 to keep the headwater elevation at a constant target pool elevation.

#### **D. Current/Future Project Operations**

The five discharge gates and lock facility at the New Savannah Bluff Lock and Dam are currently operated remotely by the U.S. Army Corps of Engineers from the J. Strom Thurmond Project. Gates 1 and 5 are typically operated as fixed overflow gates and 2 through 4 as under flow gates. Additional information is provided in Section III.C of this report. The U.S. Army Corps of Engineers will continue to operate the five discharge gates after Project transfer to the City of North Augusta and Aiken County, South Carolina, with no expected changes on the mode of operations. It should be noted that future lock operations are expected to be infrequent.



## IV Feasibility Design

### A General Boundary Conditions

#### A.1 Design Species & Characteristics

Based on site specific sampling and observations by resource agency and Clemson University scientists, the following target species were presented and discussed by fishery resource agency staff at a May 21, 2002, consultation meeting (FANP DE&S 2002):

| Species                 | Typical Size<br>(inches) | Typical Weight<br>(lbs) |
|-------------------------|--------------------------|-------------------------|
| Shortnose Sturgeon      | 18 to 40                 | 3 to 24                 |
| Atlantic Sturgeon       | 24 to 72                 | 10 to 200               |
| American Shad           | 12 to 28                 | 2 to 4                  |
| Hickory Shad            | 12 to 24                 | 1 to 3                  |
| Blueback Herring        | 10 to 15                 | 0.5                     |
| Robust Redhorse         | 12 to 28                 | 2 to 17                 |
| Striped Bass            | 12 to 60                 | 1 to 40                 |
| American Eel (upstream) | 2 to 12                  | 0.1 to 0.5              |
| (downstream)            | 18 to 30                 | 1 to 5                  |

The goal of the resource agencies is to pass all species of fish found in the Savannah River at NSBL&D. However, for the purpose of this fishway bypass system, emphasis will be placed on American shad, sturgeon, robust redhorse, striped bass and American eel. Resource agency personnel concluded if passage is provided for these species, most others will be well served.

Swim speed is an important aspect in the design of a fish passage facility. A variety of factors [water temperature, size of fish, species characteristics of fish, (Clay 1995)] affect the swim speed of target species. Historically, technical fishways have been designed on the basis of burst swim speeds of jumping fish like salmon. However, NSBL&D does not have any target species that jump to progress upstream. Therefore, the intent of this system is to keep water velocities lower than the target species swimming ability and provide adequate resting pools.

While some species may have good swimming potential, species-specific characteristics influence fishway design. Some important species-specific concerns that need to be considered are:

- American shad are easily confused by variable currents and turbulence;
- Atlantic sturgeon have a minimum passage area requirement of 3 feet wide by 2 feet deep (FANP DE&S 2002);

- Striped bass go through fish lifts and locks in large numbers with entrance velocities of 4 to 6 ft/sec; there is some data on passing shortnose sturgeon through a lift (Kynard 1998). In personal communications with Boyd Kynard, he stated that in his experience, shortnose sturgeon in the north have a swimming ability of 1.5 m/s for a distance of 20 meters. On the Connecticut River shortnose sturgeon successfully enter the lift at Holyoke Dam with an average entrance velocity of 2 m/s. However, Kynard stated that the southern shortnose sturgeon is not as good a swimmer, and he feels that a swim speed of 1 m/s over a 20 meter distance would be a more realistic design criteria for Savannah River shortnose sturgeon;
- Because of the flexible timing and unique movement patterns of the catadromous American eel, it was stated at the meeting May 21, 2002 (FANP DE&S 2002) that a fishway specific to eels is not required at this time.

Based on the wide variety of hydraulic design considerations listed above, it is clear that in order for a fishway at NSBL&D to be successful for all the target species, a large variety of hydraulic conditions need to be present in the same fishway. The benefit of a nature-like rock ramp fishway is that it provides a variety of velocities and depth, over a range of flows, to suit the numerous target species. While technical fishways are usually designed to create a very uniform and controlled hydraulic environment to accommodate one species of fish, a nature-like rock ramp fishway is designed to imitate natural stream hydraulics where a broad array of hydraulic conditions are often present in a given channel segment.

In this report, velocities in the rock ramp fishway channel are expressed as an average cross section velocity, however, it is important to keep in mind that point velocities at any given location will vary over a wide range around the average value.

## A.2 Design Fishway Capacity

There is currently no determination of the escapement required for fish passage at NSBL&D. USFWS has stated that for American shad, a restored population may be estimated by multiplying available habitat by 50 shad per acre. However, estimates of available habitat have not been made available. Based on the vertical slot fishway layout in the October 25, 2000 DOI memorandum (FANP DE&S 2002), a rough projected capacity can be determined. The DOI design criteria for that fishway was a capacity of about 15,000 pounds of fish per hour. If the DOI standard design criteria is assumed (the fishway is sized to pass 10 percent of the run in one day and 15 percent of the peak day's run in one hour), the vertical slot fishway would accommodate an annual shad run of approximately 200,000 fish. Species overlap would reduce this capacity, but the DOI fishway is sized for the maximum rate of passage during the single peak hour of the year. Utilizing these criteria, it is assumed that sufficient capacity would be available for all species during the remaining time.

Fishway capacity will not be a critical design issue for the nature-like rock ramp fishway. Unlike technical fishways such as lifts that have hopper dimensions and cycling times to consider or ladders that have limited conveyance flow and small slot dimensions to consider, the rock ramp will have a typical channel width of 75 to 90 feet and depths of 3 to 5 feet.

Therefore, the design assumption is that capacity of the rock ramp fishway is well beyond any projected needs and not a design constraint.

### A.3 Design Flow Requirements

During the Phase I Feasibility Study effort, it was generally agreed upon that the fishway bypass system should be operational within the following range of river flows:

|                    |            |                           |
|--------------------|------------|---------------------------|
| Minimum River Flow | 3,600 cfs  | Percent Exceedence ~98 %  |
| Maximum River Flow | 20,000 cfs | Percent Exceedence ~ 10 % |

The minimum flow requirement at the site is 3,600. At flows greater than 20,000 cfs, all five gates are pulled from the water and head becomes negligible, allowing free up and downstream fish passage past the project site.

Furthermore, a 600 cfs attraction flow (through the fishway) was adopted as the design basis according to resource agency recommendations. The rock ramp fishway is designed to pass a minimum of 600 cfs at low headwater, and passively adjust upward over the design head range as follows:

| Upper Pool Elevation<br>(NGVD) | Upper Pool<br>(Gauge Reference) | Resulting Design<br>Attraction Flow (cfs) | Percent<br>Exceedence |
|--------------------------------|---------------------------------|-------------------------------------------|-----------------------|
| 115.5 (Maximum Design)         | 14.92                           | 1,150                                     | 15 %                  |
| 114.5 (Average Design)         | 13.92                           | 800                                       | 50 %                  |
| 113.5 (Minimum Design)         | 12.92                           | 600                                       | 95 %                  |

The 600 cfs attraction flow is approximately 5 percent of the mean river flow during the upstream spawning migration period (February through June). The attraction flow could be reduced to 5 percent of mean flow during drier seasons. However, since the diversion of water through the fishway does not interfere with lock or other project operations, seasonal adjustments in attraction flow are not anticipated.

### A.4 Design Pond Elevations

#### A.4.1 Upstream

Based on the historic project operation procedure, it is expected that the headwater will be controlled remotely to maintain a head pond target elevation of 114.5 feet, with a normal operating variation between 113.5 feet and 115.5 feet. Resource agency personnel have indicated a concern with the discharge through Gate 5 interfering with attraction flows to the upstream fishway entrance. Gate 5 has a crest elevation of 112.5 feet. Based upon flow depths of 1 foot (at a 113.5 foot pond elevation), 2 feet (at 114.5), and 3 feet (at 115.5), the approximate discharge over the 60 foot wide gate would be 200 cfs, 550 cfs, and 1,000 cfs, respectively. Approach velocities to the gate would be approximately 0.2 fps, 0.5 fps and 0.9 fps, but would dissipate quickly upstream of the gate. Since the field of influence does not go very far upstream of the gate, it is not expected to interfere with fishway attraction flow or result in upstream migrant fallback.

#### **A.4.2 Downstream**

The normal Project tailwater elevation is 99.5 feet and the extreme low tailwater elevation is 98.0 feet. On the downstream side of Gate 5, the dam apron and stilling basin is at elevation 90.5 feet. The average discharge velocity across the stilling basin at extreme low tailwater would be approximately 0.35 to 1.8 fps over the expected operating range of gate of Gate 5 described above, and the discharge velocity will decrease as tailwater elevations increase.

### **B Project Configuration Studies and Results**

#### **B.1 Rock Ramp Channel and Weir Configuration**

##### **B.1.1 Objectives**

The objective of the proposed rock ramp fishway is to provide numerous fish species access to upstream habitat for spawning, feeding, and shelter. To provide this access, the fishway is designed to provide a range of velocities and depths preferred by the target fish species. The fishway is designed to be self-regulating over a 2 foot headwater variation, including a range of river flows from 3,600 to 20,000 cfs. The fishway will also provide an alternative downstream passage route for those fish that reject the high velocity gradient that may exist at the gate structures of the dam.

Although not a design criteria, there is also the potential for some fish species that prefer Piedmont rocky shoal habitat, to spawn or take up residence within the fishway.

##### **B.1.2 General Design Criteria**

The following list includes the general target criteria considered during development of the rock ramp fishway design:

- Range of pool depths to accommodate numerous species
- Range of water velocities within the rock ramp to accommodate numerous species
- Zone of passage for sturgeon with no vertical obstruction greater than 9 inches
- Minimum attraction/transport flow of 600 cfs
- Entrance adjacent to Gate Five discharge downstream of entrained air turbulence
- Ramp from tailrace river bed to fishway for bottom moving upstream migrants
- Ramp from fishway to forebay river bed for bottom moving downstream migrants
- Self-regulating over 2 foot headwater and 17.5 foot extreme tailwater variation
- Minimize sharp-edge shadows that might delay shad migration
- Resting pools within rock ramp fishway
- Slope of channel 3% or below
- Maintain channel stability
- Allow for adjustments in flow and velocity within weir and boulder slots
- Use standard components
- Access road to the left side of the dam

- Water control gates for fishway maintenance and access to left side of the dam
- Limit vertical water velocity components and balance vertical slot velocities
- Allow for trash handling and removal
- Crane access road along the fishway for boulder adjustments and trash handling

### B.1.3 Development of the Rock Ramp Layout

A concept layout was developed for the widest practical rock ramp within the available real estate. Figure 3 is a section for the proposed rock ramp looking downstream. It is 75 ft. wide, has a deeper center, and slopes up the inside of the bend. This is a generic layout indicating the three ranges of flow and general dimensions. For clarity it is shown without the rock weirs.

The following calculations are in accordance with industry standards for approximating hydraulic forces, flow velocities and component stability. To accommodate the final project design, physical and/or computational fluid dynamics (CFD) modeling is recommended to verify the assumptions used in this 35% design process.

#### B.1.3.1 Channel Flow

The rock ramp will be constructed on a minimum 2 foot thick bed of riprap placed over a 6 inch stone bed and filter fabric (Figure 3). Georgia Dept. of Transportation Type 1 (or equal) riprap appears to meet the stability criteria under maximum potential discharge conditions within the rock ramp channel.

| Severe Drainage Conditions or Moderate Wave Action<br>(Type 1)*                              |                    |                      |
|----------------------------------------------------------------------------------------------|--------------------|----------------------|
| Size By Volume                                                                               | Approximate Weight | Percent Smaller Than |
| 4.2 ft. <sup>3</sup><br>(0.12 m <sup>3</sup> )                                               | 700 lbs (320 kg)   | 100%                 |
| 1.8 ft. <sup>3</sup><br>(0.05 m <sup>3</sup> )                                               | 300 lbs (135 kg)   | 50%-90%              |
| 0.8 ft. <sup>3</sup><br>(0.02m <sup>3</sup> )                                                | 125 lbs (55 kg)    | 20%-65%              |
| * Between 0% and 15% of the Type 1 riprap shall pass a 4 inch (100 MM) square opening sieve. |                    |                      |

The flow through 2 foot deep riprap (within the voids) can be estimated by using an expression developed by Abt (1991). His work at slopes between 1% and 20% indicates that  $D_{10}$  provided the highest correlation to the coefficients developed. The linear regression analysis yielded the expression:

$$V_i = 0.23(gD_{10}S)^{1/2}$$

$V_i$  = average interstitial velocity in feet per second

$g$  = acceleration due to gravity in  $\text{ft/sec}^2$

$D_{10}$  = 4 inches

$S$  = gradient expressed in decimal form

$$V_i = 0.23 \left( (32.2)(4)(0.03) \right)^{1/2}$$

$$V_i = 0.45 \text{ ft/sec.}$$

The volume of flow through the riprap changes with water depth:

$$Q \text{ 3.5 ft. deep} = 58 \text{ cfs}$$

$$Q \text{ 4.5 ft. deep} = 66 \text{ cfs}$$

$$Q \text{ 5.5 ft. deep} = 75 \text{ cfs}$$

This flow must be considered for determining total velocities through the gate opening.

### B.1.3.2 Hydraulic Resistance

To get a perspective of the flow through the rock ramp channel without boulder weirs, the Manning Equation can be used:

$$V = 1.49 R^{2/3} S^{1/2} / n$$

There are a number of ways to determine Manning "n" values depending on the roughness of the channel. Using the table from Alaska Dept. of Highways Hydraulics Design Manual, the n for 1.7 ft. diameter rock would be about 0.038. (Figure 6)

Using the calculated velocity times the flow area, the approximate channel flows would be:

| Depth of Flow (ft) | Flow (cfs) | Avg. Velocity (ft/sec) |
|--------------------|------------|------------------------|
| 3.5                | 1750       | 11.6                   |
| 4.5                | 3000       | 13.8                   |
| 5.5                | 4800       | 15.8                   |

As a result of the horseshoe configuration, the velocities on the outer edge could be 33% higher than the above average velocities (Figure 7). It would be very difficult to get the target species consistently up the ramp and particularly difficult to achieve passage through the gate structure. Thus, these flows and resulting velocities are unacceptable for fish passage.

### B.1.3.3 Boulder Weir Flow

The project design uses boulder weirs at about 25 foot intervals (Figure 4). The maximum head is 115.5 feet minus 98 feet or 17.5 feet. By installing approximately 23 rock weirs, the overall drop per weir system is approximately 9 inches. Between the weirs there are resting pools. Flow adjustment and micro fish passage channels are realized by using the two-tier



boulder weir system illustrated on Figure 4. The channel bottom is lowest in the center (Figures 3 & 5). The weirs are set in an arch pattern to direct the flow to the center. There are 4 and 5 foot boulders spaced with 4 and 5 foot vertical slots between them.

On some rock ramp projects the boulder weir arch is designed with intermediate low sill stone between the boulders to make a self-supporting arch. However, a low sill may impede the passage of sturgeon, so the sill stone has not been considered in this design.

It is difficult to exactly calculate the flow through a weir system but simplified approximation can be achieved. The two weirs forming each step reduce the head loss to about 4.5 inches (0.375 feet) per weir. The average velocity generated by a 0.375 foot head is 4.9 fps ( $h = V^2/2g$ ). In fishway design there are a variety of slot coefficients between 0.75 and 1.04 that are used. Since the boulder shapes are unknown, a coefficient of 1 is proposed. A section (Figure 5) was taken along the center of the upstream primary boulder line. By taking the cross-sectional flow area between each boulder and multiplying it by the average velocity, an approximation of the flow for each flow depth can be computed.

Area 3.5 foot water depth 104 sf x 5 ft/sec = 520 cfs surface flow

Area 4.5 foot water depth 147 sf x 5 ft/sec = 735 cfs surface flow

Area 5.5 foot water depth 216 sf x 5 ft/sec = 1080 cfs surface flow

There may be some concern that the 5 ft/sec velocity would tax some species. This is the benefit of the rock ramp; it provides a range of velocities and depths. Work done by Acharya, (2001) points out that a tiered boulder spacing weir system can provide micro channels that are significantly below average velocities (Figure 4). There is also the vertical velocity profile shown in Figure 2. On the right (shallow) side of the channel, roughness will have a greater effect in reducing velocities on the inside of the channel bend.

#### **B.1.3.4 Velocities of Flow Through Gate Openings**

The head gate structure will be installed for maintenance. The proposed system utilizes 8 gates that are 7 feet wide. The gate sills will be flush with the concrete to facilitate sturgeon passage. At low head they flow 3.5 feet deep, average head 4.5 feet deep, and high head 5.5 feet deep. The average velocity through the gates is computed by adding the through flow and the surface flow and dividing by the gate area.

As shown below, the flow velocity at certain flow depths exceeds the criteria set for sturgeon of less than 3 ft/sec. However, Figure 2 indicates that the bottom velocity is approximately 66% of the average river channel velocity. It should be noted that due to the smooth concrete surface (in the head gate area), the flow velocity profile may be more uniform (i.e. less bottom drag than compared to a natural stream). In any event, should field measurements indicate that velocities are too high; an additional boulder weir may be installed either up or down stream of the gate to attain the stipulated velocity criteria.

| Flow Depth (ft) | Flow (cfs)         | Flow Area (sf) | Flow Velocity (ft/sec) | Velocity Head (ft) |
|-----------------|--------------------|----------------|------------------------|--------------------|
| 3.5             | $520 + 58 = 578$   | 196            | 2.94                   | 1.6                |
| 4.5             | $735 + 66 = 801$   | 252            | 3.17                   | 1.9                |
| 5.5             | $1080 + 75 = 1155$ | 308            | 3.75                   | 2.6                |

### B.1.3.5 Rip Rap Design

The stability of the riprap depends on:

- Weight of the rip rap material
- Gradation of the material that offers interlocking
- Depth of water (the deeper the water, the less velocity against rip rap)
- Steepness of the protected area (side slope 1:1, bottom 33:1)
- Ability of the filter blanket to prevent undermining
- Velocity of the water against the rip rap
- Submergence depth of rip rap

The average velocity in pools can be determined by taking the surface flow divided by the cross sectional area:

| Flow Depth (ft) | Flow (cfs) | Area (sf) | Channel Velocity (ft/sec) |
|-----------------|------------|-----------|---------------------------|
| 3.5             | 520        | 206       | 2.5                       |
| 4.5             | 735        | 264       | 2.7                       |
| 5.5             | 1080       | 362       | 2.9                       |

Based on the rock ramp layout, controlling design velocity for the riprap is when one of the weirs develops the full 9 inch head. This is about 7 ft/sec average velocity without taking the velocity reduction factor for depth (Figure 7). Based on Table of Equivalent Spherical Diameter of Stone in Feet (Figure 8), the 1:1 side slope would require a 0.75 ft diameter rock to resist displacement. Type 1 riprap has 45% to 80% of the material larger than 1.1 ft diameter. Thus, the side slope riprap at a 1:1 slope is stable if properly placed.

### B.1.3.6 Boulder Stability

#### *Condition 1: Two-Tier Boulder System - Stability of Lower Center Boulder*

A simplified approach to boulder stability uses the following criteria:

- Static head 0.375 ft. – Straight-line conservative approximation of 23.4 psf
- Velocity head based on 0.375 ft. head drop per weir = 5 ft/sec (possible on downstream boulder)
- Density of stone 165 lb/cf
- Sliding friction coefficient of boulder on rip rap = 0.5



- Drag coefficient for boulder shape based on a two dimensional square cylinder = 2.0 applied 55% up the boulder
- For uplift calculations a straight-line approximation was used with a head differential of 0.375 ft.
- Since the shape and support for each boulder can vary, moments were taken about a point 1 ft upstream of the downstream-most edge for each condition

(See Figure 8 For Loading Diagram)

#### 4 Ft. Boulder Overturning & Sliding

$$C_D = C_P + C_F$$

$$\text{Drag force} = C_D A \rho V^2 / 2 = 2(4' \times 4') 1.96 (5 \text{ ft/sec}^2)^2 / 2 = 784 \text{ lbs}$$

$$\text{Static head} = (23.4 \text{ lbs/sf})(4' \times 4') = 375 \text{ lbs}$$

$$\text{Weight of Stone } 4' \times 4' \times 4' (165 \text{ lbs/cf} - 62.4 \text{ lbs/cf}) = 6566 \text{ lbs}$$

$$\text{Uplift} = 4' \times 4' \times 23.4 = 375 \text{ lbs}$$

$$\text{Overturning Factor of Safety} =$$

$$(6566 \text{ lbs})(1 \text{ ft}) / (784 \text{ lbs} \times 55\% \times 4' + 375 \text{ lbs} \times 1' + 375 \text{ lbs} \times 2') = 2.3$$

$$\text{Sliding Resisting Force with .5 Coefficient of Sliding} =$$

$$\text{Resisting force} = (6566 \text{ lbs} - 375 \text{ lbs}) \times (0.5) = 3095 \text{ lbs}$$

$$\text{Sliding Load} = 784 \text{ lbs} + 375 \text{ lbs} = 1159$$

$$\text{Sliding Factor of Safety} = 3095 / 1159 = 2.7$$

#### 5 Ft. Boulder Overturning & Sliding

$$C_D = C_P + C_F$$

$$\text{Drag force} = C_D A \rho V^2 / 2 = 2(5' \times 5') 1.96 (5 \text{ ft/sec}^2)^2 / 2 = 1225 \text{ lbs}$$

$$\text{Static head} = (23.4 \text{ lbs/sf})(5' \times 5') = 585 \text{ lbs}$$

$$\text{Weight of Stone } 5' \times 5' \times 5' (165 \text{ lbs/cf} - 62.4 \text{ lbs/cf}) = 12825 \text{ lbs}$$

$$\text{Uplift} = 5' \times 5' \times 23.4 = 585 \text{ lbs}$$

$$\text{Overturning Factor of Safety} =$$

$$(12825 \text{ lbs})(1.5 \text{ ft}) / (1225 \text{ lbs} \times 55\% \times 5' + 585 \text{ lbs} \times 2.5' + 585 \text{ lbs} \times 1.5') = 3.4$$

$$\text{Sliding Resisting Force with .5 Coefficient of Sliding} =$$

$$\text{Resisting force} = (12825 \text{ lbs} - 585 \text{ lbs}) \times (0.5) = 6120 \text{ lbs}$$

$$\text{Sliding Load} = 1225 \text{ lbs} + 585 \text{ lbs} = 1810 \text{ lbs}$$

$$\text{Sliding Factor of Safety} = 6120 / 1810 = 3.4$$

#### ***Condition 2: Stability of Single-Tier Boulder System***

A simplified approach to this condition uses the following criteria:

- Static head of 0.75 ft or 46.8 psf

- Velocity head based on 0.7 ft head drop per weir = 7 ft/sec. between boulders. Figure 7 has an approach velocity of 2.7 ft/sec for a fully submerged stone.
- Density of stone = 165 lbs/cf
- Sliding coefficient of boulder on rip rap = 0.5
- Drag coefficient for boulder shape = 2 (based on a square cylinder) applied 55% up the boulder
- For uplift calculations a straight-line approximation was used with a head differential of 0.75 ft.
- Since the shape and support for each boulder can vary, moments were taken about a point 1 ft upstream of the downstream-most edge for each condition
- Friction drag coefficient = 0.003 (Ahmen 1987 pg 402)

#### 4 Ft. Boulder Overturning & Sliding

$$\text{Friction Drag Force} = C_F A \rho V^2 / 2 = (0.003)(1.96)(7\text{ft/sec}^2)^2 (4' \times 4' \times 2) / 2 = 4.6 \text{ lbs}$$

$$\text{Pressure Drag Force} = C_P A \rho V^2 / 2 = 2 (4' \times 4') 1.96 (2.7\text{ft/sec}^2)^2 / 2 = 229 \text{ lbs}$$

$$\text{Static head} = (46.8 \text{ lbs/sf})(4' \times 4') = 749 \text{ lbs}$$

$$\text{Weight of Stone } 4' \times 4' \times 4' (165\text{lbs/cf}-62.4 \text{ lbs/cf}) = 6566 \text{ lbs}$$

$$\text{Uplift} = 4' \times 4' \times 46.8 = 749 \text{ lbs}$$

$$\text{Overturning Factor of Safety} =$$

$$(6566 \text{ lbs})(1\text{ft}) / (229 \text{ lbs} \times 55\% \times 4' + 749 \text{ lbs} \times 2' + 749 \text{ lbs} \times 1' + 4.6 \text{ lbs} \times 55\% \times 4) = 2.4$$

$$\text{Sliding Resisting Force with .5 Coefficient of Sliding} =$$

$$\text{Resisting force} = (6566\text{lbs} - 749\text{lbs}) \times (0.5) = 2909 \text{ lbs}$$

$$\text{Sliding Load} = 749 \text{ lbs} + 4.6 \text{ lbs} + 229 \text{ lbs} = 983 \text{ lbs}$$

$$\text{Sliding Factor of Safety} = 2909/983 = 3.0$$

#### 5 Ft. Boulder Overturning & Sliding

$$\text{Friction Drag Force} = C_F A \rho V^2 / 2 = (0.0035) (5' \times 5' \times 2) (1.96)(7\text{ft/sec}^2)^2 / 2 = 8.4 \text{ lbs}$$

$$\text{Pressure Drag Force} = C_P A \rho V^2 / 2 = 2 (5' \times 5') 1.96 (2.7\text{ft/sec}^2)^2 / 2 = 357 \text{ lbs}$$

$$\text{Static head} = (46.8 \text{ lbs/sf})(5' \times 5') = 1170 \text{ lbs}$$

$$\text{Weight of Stone } 5' \times 5' \times 5' (165\text{lbs/cf}-62.4 \text{ lbs/cf}) = 12825 \text{ lbs}$$

$$\text{Uplift} = 5' \times 5' \times 46.8 = 1170 \text{ lbs}$$

$$\text{Overturning Factor of Safety} =$$

$$(12825 \text{ lbs})(1.5\text{ft}) / (357 \text{ lbs} \times 55\% \times 5' + 1170 \text{ lbs} \times 2.5' + 1170 \text{ lbs} \times 1.5' + 8.4 \text{ lbs} \times 55\% \times 5') = 3.4$$

$$\text{Sliding Resisting Force with .5 Coefficient of Sliding} =$$

$$\text{Resisting force} = (12825\text{bs} - 1170\text{lbs}) \times (0.5) = 5828 \text{ lbs}$$

$$\text{Sliding Load} = 1170 \text{ lbs} + 8.4 \text{ lbs} + 357 \text{ lbs} = 1535 \text{ lbs}$$

$$\text{Sliding Factor of Safety} = 5828/1535 = 3.8$$

### **B.1.3.7 Entrance and Exit Considerations**

#### ***Fishway Entrance***

The location of the entrance is critical to good fish passage. According to the agencies, the following general observations with respect to fish movement have been noted:

- Fish move up the river below the navigation lock along the right side (looking downstream) of the river.
- Fish move across the spillway from right to left and congregate in the area of Gate 5 (closest to the South Carolina side of the river).

As a result, it was agreed upon that for a horseshoe rock ramp configuration, the upstream entrance below Gate 5, should be located as close to the spillway as possible and in an area where turbulence from the gate discharge does not distract from its effectiveness.

#### ***Fishway Exit***

It is important that the upstream exit, above Gate 5, be located in an area that has a water velocity equal to, or greater than the threshold velocity of the fish leaving the exit. The threshold velocity leads the fish for orientation away from the Gate 5 area, and it can be as low as 1 cm/sec (Clay 1995). However, the water velocity must also be less than the critical velocity (maximum sustained swimming speed of the target fish) when the flow downstream is great enough to sweep the fish over the dam.

### **B.1.4 Resulting Configuration**

The resulting configuration of the fish bypass canal is shown on drawings titled Savannah 3 through Savannah 6 within Appendix A. The canal is approximately 650 feet in length, installed on a grade of 3 percent and utilizes a modified trapezoidal cross section measuring 75 feet wide at the base with 1H:1V side slopes.

To best achieve the desired flow conditions within the canal, rock weirs are placed on a radial pattern located approximately 25 feet on centers. On the outside section of the canal 5 ft. boulders are located on approximately 5 ft. spacing. On the inside section of the canal, 4 ft. boulders are spaced on 4 ft. centers with intermediate placements between the radial weirs to create slower flow velocities and resting pools.

The entire canal is protected from erosion by a 2 ft. layer of riprap placed over bedding stone and filter fabric. The downstream entrance/exit invert elevation is 93.0 and is located as close to Gate 5 area as possible. There will be a transition area between elevation 93.0 and elevation 85.0 along the downstream bank that will receive an application of rip rap to create a more smooth transition from the natural river bottom to the man-made canal. The upstream exit/entrance invert elevation is 110.0 and is also strategically located to enhance the movement of both upstream and downstream fish movement. Similar to that downstream,

riprap will extend from the invert elevation 110.0 to approximately elevation 95 to provide a smooth transition from the natural river bed to the canal entrance.

A headwater control structure will be located at the upstream entrance to the canal and is addressed in further detail in Section IV.B.2 of this report.

To reduce the accumulation of debris just upstream of the headwater control structure, it is recommended that a floating trash boom be installed.

## **B.2 Headwater Control Structure**

### **B.2.1 Objectives**

The primary objectives of the Headwater Control Structure are as follows:

- Provide a means to isolate the canal from the Savannah River in the event that maintenance is required along the fish bypass channel;
- Provide sufficient opening area and flow bypass characteristics to allow all target species the ability to move through the bypass system without velocity barriers;
- Provide rolling stock access to the left abutment of the New Savannah Bluff Lock & Dam Structure if required;
- To provide a cost effective and passive system with minimal future maintenance; and,
- Provide access and structures to accommodate future fish monitoring activities, as required by the resource agencies.

### **B.2.2 General Design Criteria**

The headwater control structure will be designed in accordance with the following:

#### ***Operating Design Conditions:***

##### Condition A - Normal Operating

Headwater Elevation – Between Elevation 115.5 and 113.5

All Gates – Open Position

##### Condition B – Normal Canal Maintenance Condition

Headwater Elevation – Between Elevation 115.5 and 113.5

All Gates – Closed Position

##### Condition C – Extreme Canal Maintenance Condition

Headwater Elevation – Elevation 118.72 (Max, Recorded Elev. Post 1/11/92)

All Gates – Closed Position

**Other Design Assumptions:**

- Any stabilizing effects and/or contributions from the sheet pile wall is neglected (Conservative)
- The structure shall be designed for the full hydrostatic head and associated uplift (Conservative)
- The structure will be designed on a per foot basis without stability contributions from the structure / abutment interface (Conservative)

**Minimum Factors of Safety:**

Listed below are the minimal factors of safety for the various operating conditions:

| Condition                     | Overturning | Sliding |
|-------------------------------|-------------|---------|
| A – Normal Operating          | 1.5         | 1.5     |
| B – Normal Canal Maintenance  | 1.5         | 1.5     |
| C – Extreme Canal Maintenance | 1.2         | 1.2     |

**B.2.3 Methodology & Analysis**

Conventional calculations were performed for both the structural overturning and sliding. A copy of the calculation is provided in Appendix H.1. Listed below are the results of this analysis.

| Condition                     | Overturning | Sliding |
|-------------------------------|-------------|---------|
| A – Normal Operating          | >> 2.0      | >> 2.0  |
| B – Normal Canal Maintenance  | 1.81        | 2.31    |
| C – Extreme Canal Maintenance | 1.33        | 1.33    |

**Note:** Even though the factor of safety for overturning is 1.33 for the condition of extreme canal maintenance, the analysis is considered very conservative due to the conservation nature of the calculation (i.e. not all of the resisting loads were utilized). Had all of the contributing resisting forces been included, factors of safety for the extreme conditions greater than 1.5 would be expected. Furthermore, the gates will only be lowered and the canal isolated for routine maintenance. Canal maintenance during extreme flooding conditions is considered to be an unreasonable design condition.

Due to the need for mass concrete, the level of concrete reinforcement required is expected to be controlled by  $\rho$  minimum (crack control only).

**B.2.4 Resulting Configuration**

Listed below is a brief description of the headwater retaining structure. Additional details of the structure are provided on Drawings provided in Appendix A.

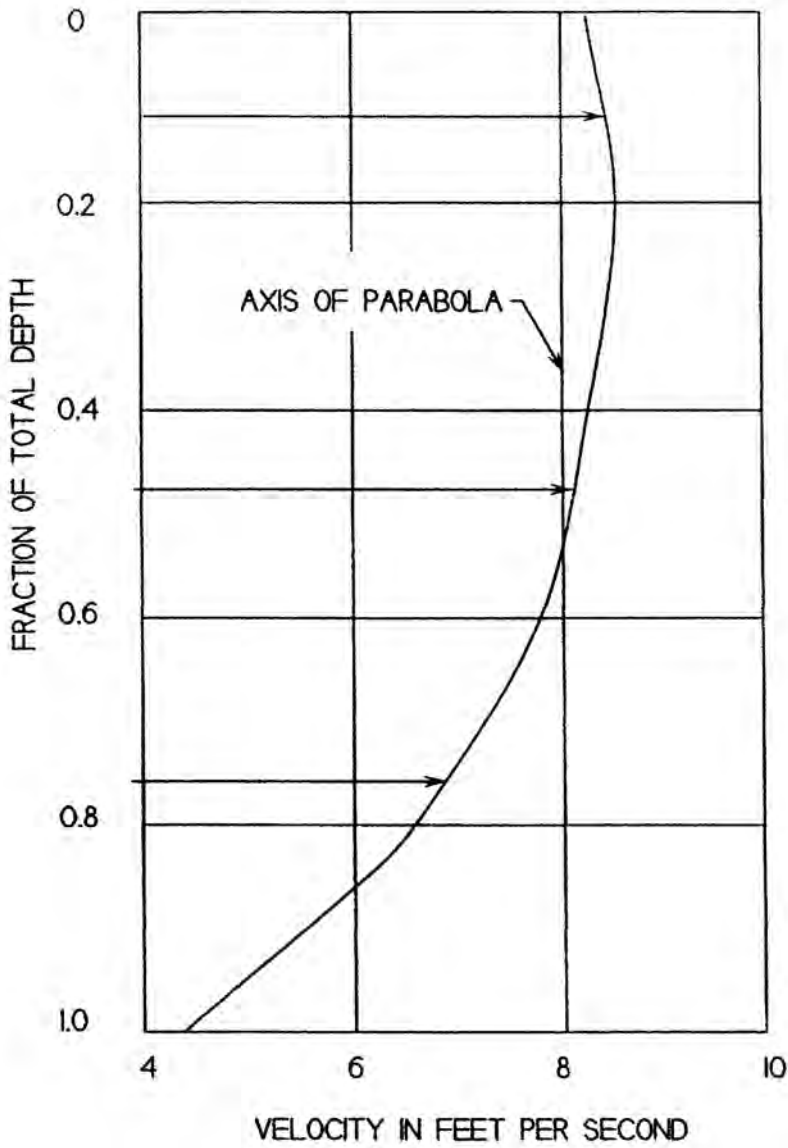
The reinforced concrete headwater control structure will be located at the upstream entrance to the canal approximately 20 feet from the river edge. The structure will span the fish bypass canal measuring approximately 105 feet wide. The top of the structure will be at elevation 120 and the invert elevation established at 108.0. The crest of the structure will measure 8 feet wide and provide approximately 5 feet of unobstructed authorized access. Hand rails along each side of the structure will be provided along with removable grating covering the stop long slots.

The structure will be constructed with 8 gate openings measuring 7 feet wide and 8 feet tall. Each gate opening will be installed with slide gates fabricated of non-corrosive materials. Each gate will be provided with manual operators. In the event it becomes necessary to isolate a gate, one set of stop logs will be provided. The threshold for each gate will be flush with the structure invert and provide smooth passage for migrating fish. For additional details regarding the proposed gate system, please refer to Appendix I.

In order to control seepage both under and around the structure, a sheet pile cut-off wall is proposed. This cut-off wall would be installed to a minimum elevation of 92.0 and extend from the existing dam wing wall through the structure, terminating approximately 30 feet beyond the structure in the easterly (upstream) direction.

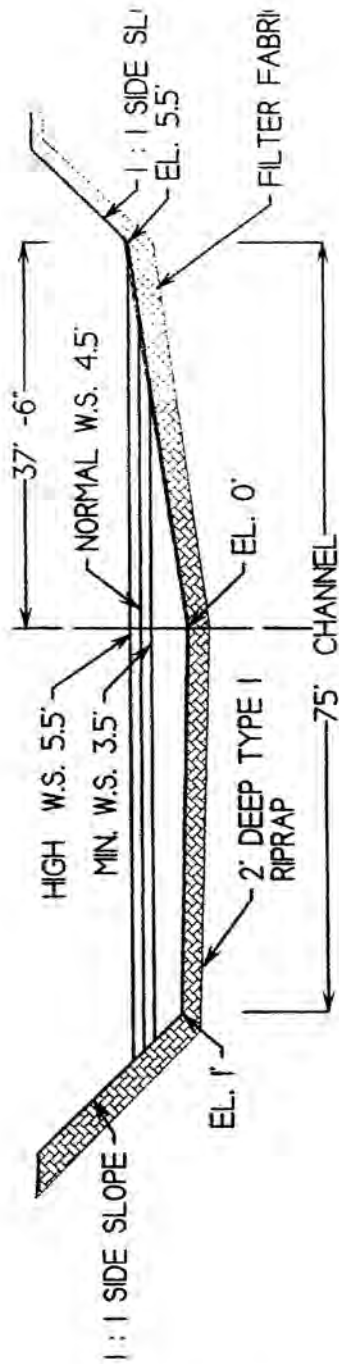
All metallic surfaces would be properly coated to prohibit corrosion and minimize long-term maintenance.

The USACE has proposed tapping into an electrical source on the existing dam structure for future electrical needs if required.



A TYPICAL VERTICAL VELOCITY PROFILE IN A STREAM  
ADAPTED FROM LINSLEY, 1958

**FIGURE 2**



TYPICAL CHANNEL SECTION  
ACROSS THE FLOW (WITHOUT BOULDERS)  
LOOKING DOWNSTREAM

FIGURE 3



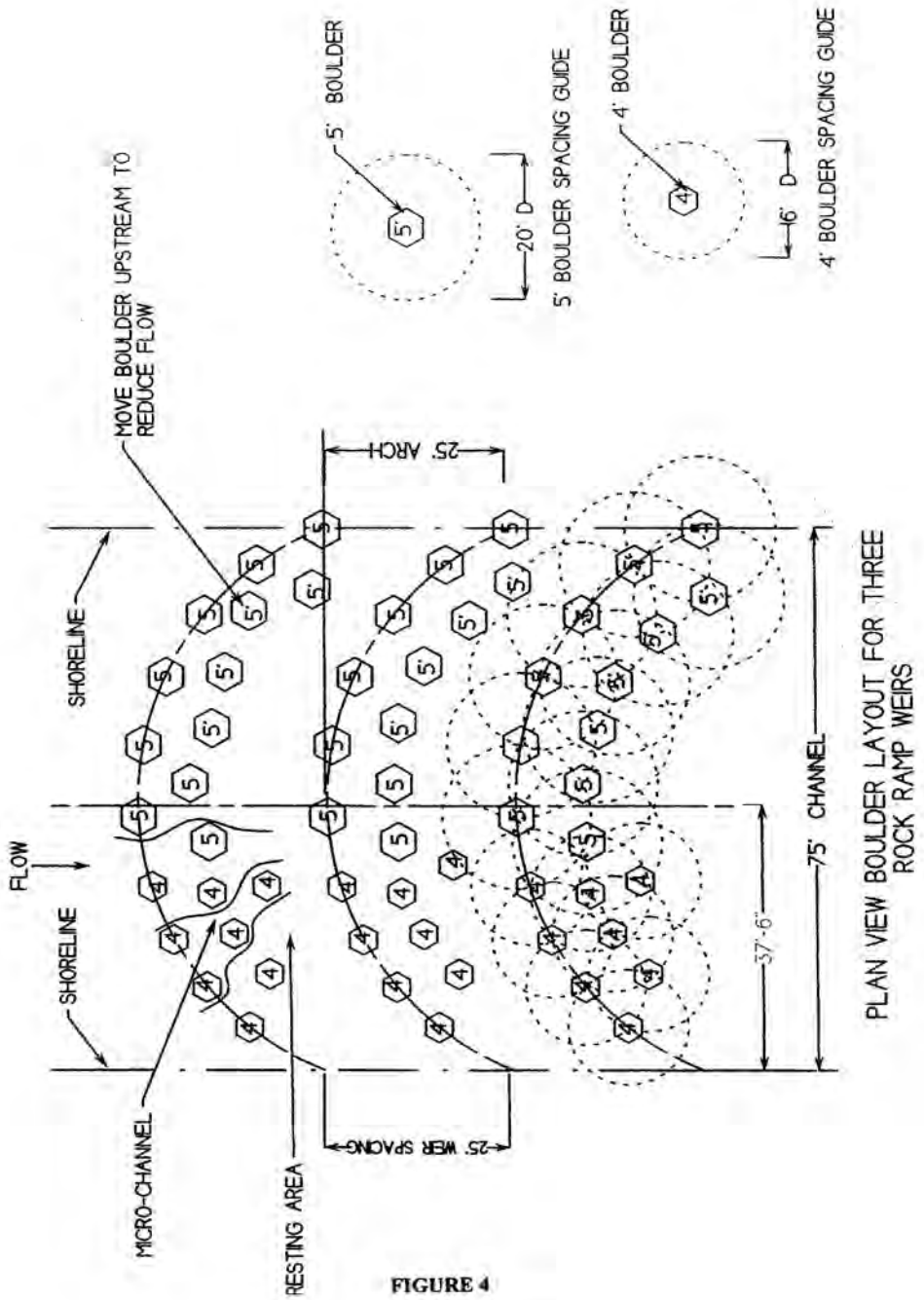
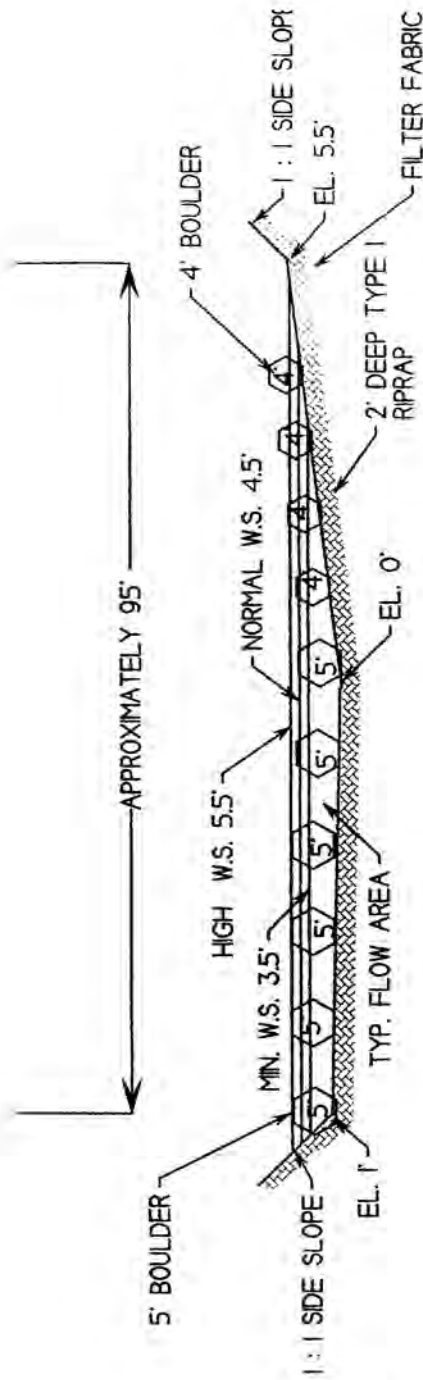


FIGURE 4



TYPICAL SECTION ALONG THE UPSTREAM BOULDER WEIR  
LOOKING DOWNSTREAM

FIGURE 5

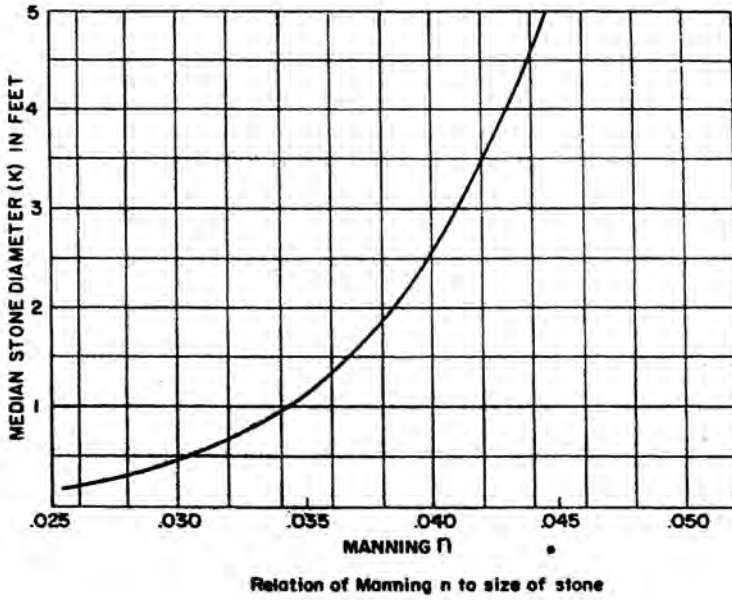
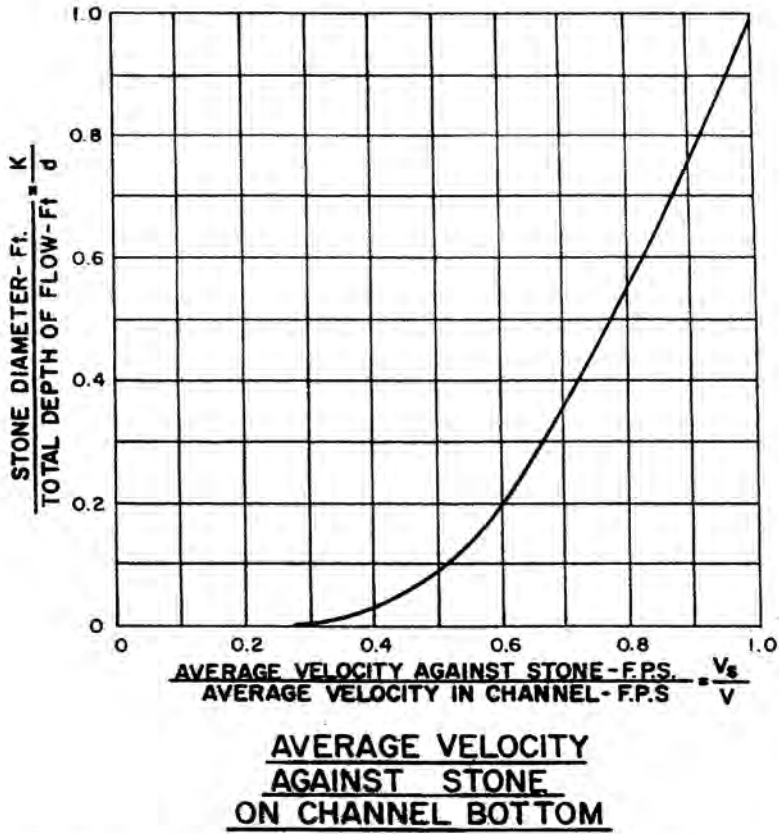


FIGURE 6

Adapted from Hydraulics Manual, State of Alaska, Department of Highways



Use Velocity in Channel =  $\frac{4}{3} \times$  (Average Velocity in Channel)  
for curved sections.

FIGURE 7

Adapted from Hydraulics Manual, State of Alaska, Department of Highways

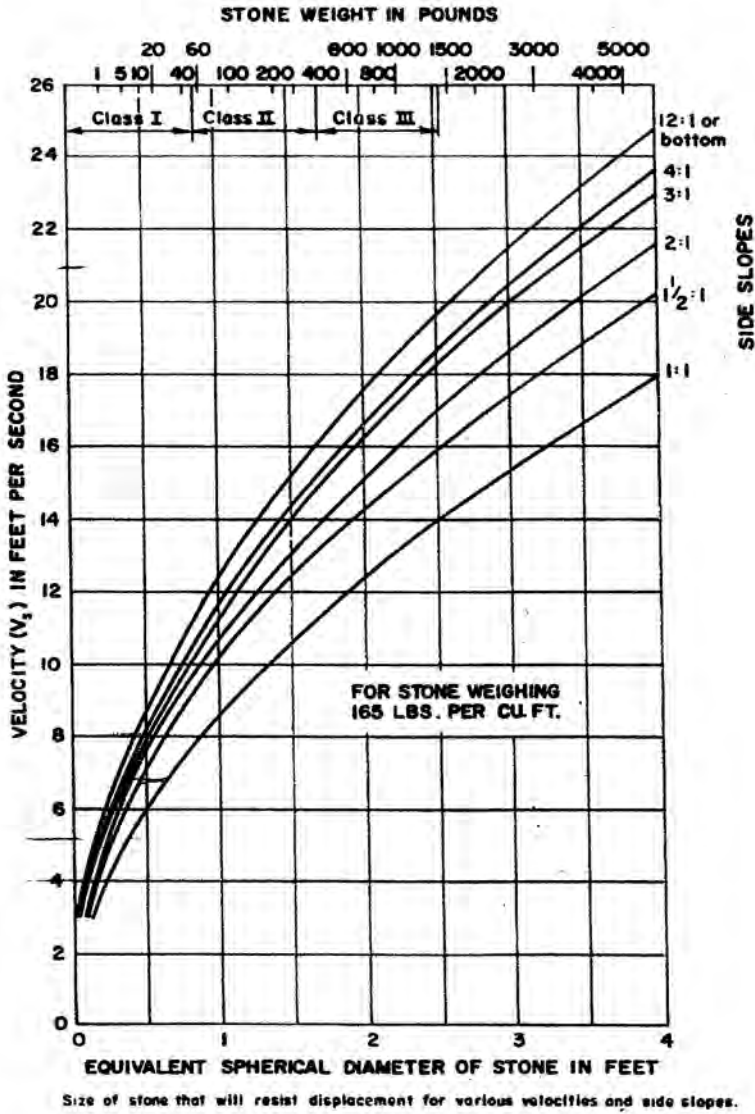
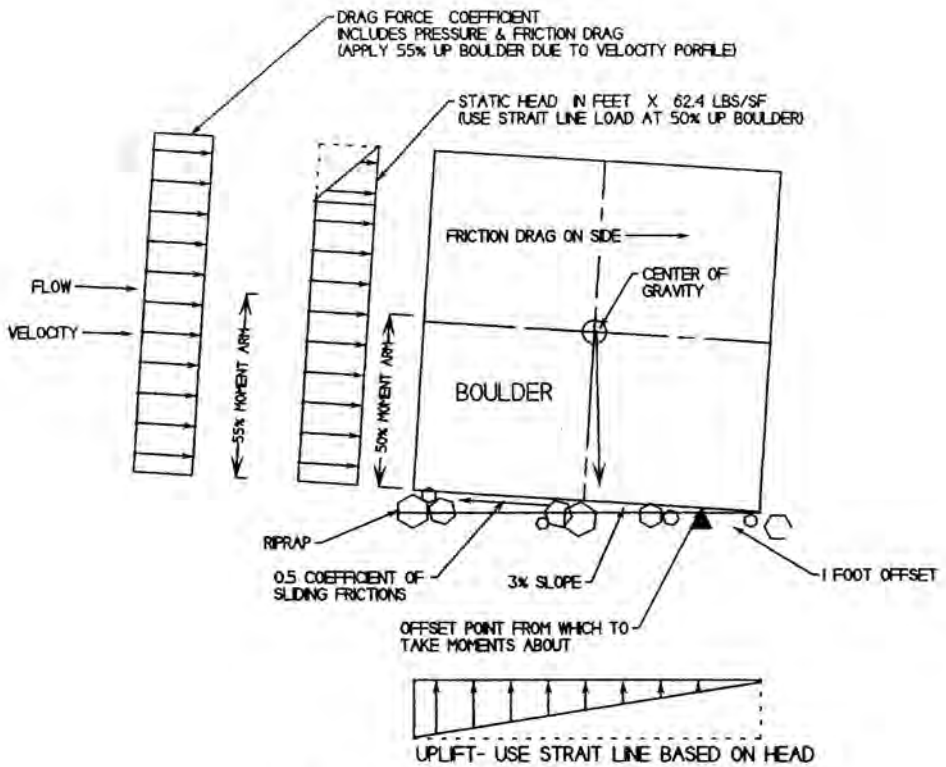


FIGURE 8

Adapted from Hydraulics Manual, State of Alaska, Department of Highways



TYPICAL BOULDER LOADING SKETCH

FIGURE 9

### **B.3 On-Site Access**

#### **B.3.1 Objectives**

It has been requested by the Corps of Engineers that access across the rock ramp fishway structure be provided as follows:

- Authorized Personnel Access – Authorized access (foot traffic) across the headwater control structure to facilitate routine maintenance, fish monitoring, etc., during periods of normal operation. It is assumed that the facility will not permit open and unobstructed access across the facility.
- Authorized Vehicular Access – In the event it becomes necessary to access the left abutment of the dam via rolling stock for required maintenance or repairs.

#### **B.3.2 General Design Criteria**

##### Personnel Access

- Allocate sufficient space for safe and unobstructed access
- Provide handrails across structure

##### Vehicular Access

- Provide “in the dry” access across canal when headwater structure gates are in the closed position
- The access road shall be constructed with a maximum grade of 15% and shall provide for a minimum turning radius of 50 feet.
- The submerged access road shall be stable and erosion resistant under design operating conditions.
- The design shall pose no detriment to overall fish passage objectives

#### **B.3.3 Methodology & Analysis**

No structural analysis required, slab thickness determined by engineering judgment.

#### **B.3.4 Resulting Configuration**

##### Personnel Access

An 8 foot wide horizontal platform provides approximately 5 feet of unobstructed personnel access along the upstream crest of the headwater control structure. For safety measures the structure will be installed with handrails and removable grating to cover the stop log openings. The handrails and grating are assumed to be fabricated of carbon steel and properly coated for corrosion resistance.

### Vehicular Access

Vehicular access ramps are provided along both the canal side slopes just downstream of the water control structure. The ramps are assumed to be 15 feet wide and constructed on a grade not to exceed 15 percent. The side slopes are assumed to be protected with riprap and the roadway covered with an 8 inch concrete slab.

## **B.4 Off-Site Access**

### **B.4.1 Objectives**

It has been requested by the Corps of Engineers that off-site access be provided to the structure as follows:

- Authorized Vehicular Access - Temporary easement during construction and long term easement to facilitate operations and maintenance.
- Barge Access - Temporary access for material delivery

### **B.4.2 Resulting Configuration**

To be determined following the receipt of information from the U.S Corps of Engineers.

## **B.5 Security**

### **B.5.1 Objectives**

Provide adequate security to the site permitting only authorized personnel and vehicular access.

### **B.5.2 Resulting Configuration**

The subject site containing the fish bypass system will be surrounded on the east, south and west by an 8 feet tall chain link fence topped with three strands of barbed wire. There will be at least one location installed with a manually operated gate measuring approximately 16 feet in width to accommodate authorized vehicular access. There will also be at least one personnel type gate access.

There are no plans for exterior lighting and/or remote monitoring.

## **B.6 Construction Methodology**

The subject fish bypass system will be constructed along the abutment of the Savannah River. To facilitate constructing much of the facility in the dry, both upstream and downstream earthen cofferdams will be utilized. Each earthen cofferdam will be constructed with 1.5 to 1 slopes and located in such a manner as to minimize the placement of fill



material into the river and yet provide the maximum space with which to construct both the canal and the headwater control structure. After completion of the canal and headwater control structure, the cofferdams will be removed with conventional earthmoving equipment and the cofferdam footprints will be lined with riprap.

The entire canal will be excavated utilizing conventional earth moving equipment. The subsurface conditions consist of silt and sandy materials and no rock should be encountered. It is desirable that the fish bypass canal be constructed in a very controlled manner to salvage as many of the existing trees as possible. Should it not be possible to salvage trees as originally thought, it is recommended that a planting program be initiated to install additional trees (i.e. river birch, willows, etc.) at various locations along the bypass canal perimeter.

During construction, there is a high degree of certainty that the excavation will require unwatering resulting from seepage from the adjacent river. In addition it may be necessary to place geotextile filter fabric and riprap along both the upstream and downstream slopes of the cofferdam to protect against the movement of fines and surface erosion.

All riprap and boulders are assumed to be delivered to the site via barge. Concrete and other materials are assumed to be delivered via overland access.

All material disposal is assumed to be off-site unless other arrangements are made and approved by all parties.

## **B.7 Testing, Commissioning and Evaluation Criteria**

### **B.7.1 Objectives**

It is expected that there will be two phases to the testing and evaluation program. Phase 1 will be to measure the physical flow and representative point velocities in the rock ramp channel over the three-target headwater ranges. The objective of Phase 1 will be to determine if the fishway hydraulics meet recognized hydraulic criteria to pass the target fish species and are within the design range.

Phase 2 testing will address the biological effectiveness of the fishway to confirm target species are passing through the fishway. Phase 2 testing is not addressed in this report.

### **B.7.2 Methodology**

The total flow data (rock ramp channel discharge) for Phase 1 may be gathered with an acoustic Doppler current meter that can take transects in the area of the gate structure at the three target headwater elevations. If an acoustic Doppler unit is not available, individual point measurements of depth, velocity and cross sectional area in the gates can be used to establish the total flow through the channel.

Also, the flows at the boulder weirs should be observed for any gross area that may inhibit fish passage with excessive velocity or turbulence. If there are apparent problems, individual

boulders can be moved to adjust flows. For a set of two boulder weirs, taking three dimensional point velocities around the boulders and within micro channels should make a more detailed velocity analysis. Temporary access from which to perform these measurements is assumed to be provided via wood planking secured to the tops of the boulders within the canal.

## **B.8 Operations and Maintenance**

### **B.8.1 Objectives**

The general consensus is that a rock ramp fishway will take less maintenance than a traditional technical fishway. The rock ramp fishway is designed to be self-regulating over the normal operation headwater range. Headwater elevation in the Savannah River is controlled by adjusting the three center dam gates from a remote location, and is coordinated with water releases from upstream projects. The velocities within the rock ramp fishway should be high enough to prevent any major bed load sediment buildup within the rock ramp channel.

### **B.8.2 Methodology**

Minor adjustments to boulder locations may be required during normal operation. To facilitate these adjustments, a mobile crane could be used. Stainless steel lifting bolts, which are anchored permanently with adhesive, or holes, which are typically drilled in large rocks for quarry work, on the boulders would allow rotating or lifting with the mobile crane. This reduces the equipment size required to move the boulders and the load to be lifted. A lifting chain/dogs can weigh less than 100 lbs. An orange peel, to move the same weight rock, could weigh 5,000 lbs.

It is recommended that a floating boom be installed just upstream of the headwater control structure in such a manner to deflect floating debris toward the direction of Gate No. 5. In any event, it may become necessary to periodically removal some debris accumulation from in front of the floating devise or either material that may possibly bypass the boom and accumulate just upstream of the headwater control structure. It is expected that small items will go right through the rock ramp fishway.

Historically, the gates on the project have been manipulated to draw large trash from the side of the river to be sluiced. If this procedure does not continue to work, a mobile crane with a grapple or a stationary hoist to draw trash from the fishway to the dam gate structure may be needed.

|                                     |
|-------------------------------------|
| <b>V      Construction Schedule</b> |
|-------------------------------------|

All project schedules, including project and construction, are to be completed by the U.S. Army Corps of Engineers or as otherwise directed by the U.S. Army Corps of Engineers.

|                         |
|-------------------------|
| <b>VI Cost Estimate</b> |
|-------------------------|

**A. Material Quantity Estimate**

Listed below is a rough estimate of major quantities necessary to construct the NSBL&D Fish Bypass System:

| Item       | Description                            | Units | Quantity |
|------------|----------------------------------------|-------|----------|
| <b>A</b>   | <b>Site Prep &amp; Temporary Works</b> |       |          |
|            | Access Roads                           | LM    | TBD      |
|            | Barge Unloading Facility               | LS    | 1        |
|            | Temporary Cofferdams                   |       |          |
|            | Filter Fabric                          | SY    | 2100     |
|            | Riprap                                 | CY    | 710      |
|            | Earthwork                              | CY    | 35000    |
|            | Utilities                              | LS    | 1        |
|            | Construction Power                     | LS    | 1        |
|            | Water Control                          | LS    | 1        |
|            | Site Laydown Area                      | LS    | 1        |
|            | Temporary Fencing                      | LF    | 1400     |
|            | Erosion Control                        | LS    | 1        |
| <b>B</b>   | <b>Civil Works</b>                     |       |          |
| <b>B.1</b> | <b>Earth Work &amp; Drainage</b>       |       |          |
|            | Clearing & Grubbing                    | Acre  | 4        |
|            | Earthwork                              |       |          |
|            | Excavation                             | CY    | 53000    |
|            | Disposal                               | CY    | 58000    |
|            | Filter Fabric                          | See   | 11000    |
|            | Riprap                                 | CY    | 7400     |
|            | Boulders                               | EA    | 500      |
|            | Rough Grading                          | Acre  | 4        |
|            | Fine Grading                           | Acre  | 4        |
|            | Canal Access Concrete Paving           | CY    | 56       |
| <b>B.2</b> | <b>Headwater Structure</b>             |       |          |
|            | Sheet Piling                           | SY    | 5250     |
|            | Concrete                               | CY    | 450      |
|            | Reinforcing                            | Ton   | 15       |
|            | Miscellaneous Steel                    |       |          |
|            | Handrail                               | LF    | 230      |
|            | Grating                                | Ton   | 1        |
|            | Miscellaneous Steel Embeds             | Ton   | 1        |
|            | Slide Gates w/Operators                | EA    | 8        |
|            | Stop Logs                              | EA    | 1        |
| <b>B.3</b> | <b>General</b>                         |       |          |
|            | Landscaping                            | LS    | 1        |
|            | Fencing                                | LF    | 1400     |
|            | Access                                 | LF    | TBD      |
| <b>C</b>   | <b>Electrical Works</b>                | LS    | TBD      |
| <b>D</b>   | <b>Mechanical Works</b>                | NA    | NA       |

## **B. Other Issues That Could Effect Installation Costs**

Listed below are several items that could affect the completed installed cost of the rock ramp fish bypass system:

### **B.1 Surgical Excavation**

Over the course of studies, there has been some discussion regarding the need to save as many trees as possible on the construction site. Due to limited space along the left abutment and the need for staging and lay down area, it may be difficult to save a large number of the existing trees. However, for the purpose of this report, it is assumed that small earth moving equipment will be utilized.

### **B.2 Testing & Commissioning**

Due to the nature of rock ramp fish bypass systems, field adjustments to weirs and boulders will be necessary during testing and commissioning to achieve the desired performance. As a result, additional money should be allocated within the budget for both a standby crane with sufficient capacity and boom. Field engineering (Fish Bypass Specialist) support will be required during commissioning to measure velocities within the rock weirs and direct boulder adjustments.

### **B.3 Off-Site Disposal of Materials**

Due to space limitations, it was decided to assume that all excavated materials would be disposed of off-site.

### **B.4 Access Limitations**

At the time of this engineering study, the availability of over land site access was unclear. As a result, it should be assumed that all material deliveries and disposals be accomplished via barge.

## **C. Cost Estimate**

The project cost estimate is to be completed by others under the direction of the U.S. Army Corps of Engineers.

## **VII Study Conclusions and Recommendations**

### **Conclusions**

The NSBL&D Project has been given a Congressional mandate to continue operation as a navigation lock, allow transfer of ownership to the City of North Augusta and Aiken County, South Carolina, and provide both upstream and downstream fish passage for a diversity of fish species, including rare and endangered species. Fish passage options are limited by the available real estate and by the restriction on structural interaction with the lock. However, the low head at this site, combined with the consistent headwater, provide an opportunity to construct a self-regulating, cost effective horseshoe-shaped rock ramp fishway. Benefits of the horseshoe rock ramp fishway are the nature-like hydraulic features for fish passage, lower capital costs and lower operating costs. An additional benefit of the rock ramp fishway is that it creates new rocky shoal habitat that some species of fish may find attractive for spawning or residence within the structure. Also, the flow control structure at the head of the rock ramp fishway can be used to enumerate and manage the fish species that migrate past this point in the Savannah River drainage.

The project is fortunate that there have been ongoing fish behavior studies of many of the target species at the NSBL&D site. The fishway entrance is the most critical aspect of effective fish passage design. The studies provided confirmation that the proposed location of the upstream passage entrance is where migratory fish congregate. The resource agencies have stated that there is a diverse species assemblage that needs both upstream and downstream passage at the site. The rock ramp fishway provides diverse hydraulic conditions in pool depth and velocity to accommodate the swimming abilities of target species. The proposed system allows flexibility in adjustment of boulder weirs if ongoing studies of fish migration indicate modifications are necessary.

There does not appear to be any technical or economic (within congressional mandated funding limits) reasons that the project could not be effectively completed. Efforts should be made to assure funding is available to complete the design and construct the project.

### **Additional Recommendations**

There should be a continued dialog between those conducting the fish migration studies at the project site, those preparing the final project design and the resource agencies. The interpretation of the fish movements must be consistent with the proposed designs.

There has been some discussion regarding additional modeling efforts, including a Computational Fluid Dynamics (CFD) computer modeling and the need to build a full-scale physical hydraulic model. Listed below are our thoughts on each, including advantages, limitations, outcome and recommendations:

### Computational Fluid Dynamics Modeling

Advantages – CFD Modeling is an excellent cost effective tool for determining head loss and flow characteristics around boulders.

Disadvantages (Limitations) – The drag coefficients are not easily modeled by the CFD method.

Recommendations – CFD Modeling should be performed during final project design.

### Physical Modeling

Advantages – A physical model could be constructed to various levels of detail, including the modeling of only individual boulders (of various sizes and shapes) to confirm drag coefficients, to a full-scale prototype to model the entire operations, including flows combinations through the bypass system and adjacent gate no. 5.

Disadvantages (Limitations) – Depending on the modeling effort (i.e. individual boulders vs. full-scale prototype modeling) the costs could escalate from around \$20,000 to over \$100,000.

Recommendations – At this point, we recommend as minimum that boulders of various sizes and shapes be physically modeled to confirm boundary conditions utilized within the CFD modeling as well as the boulder stability calculations.

## Technical References

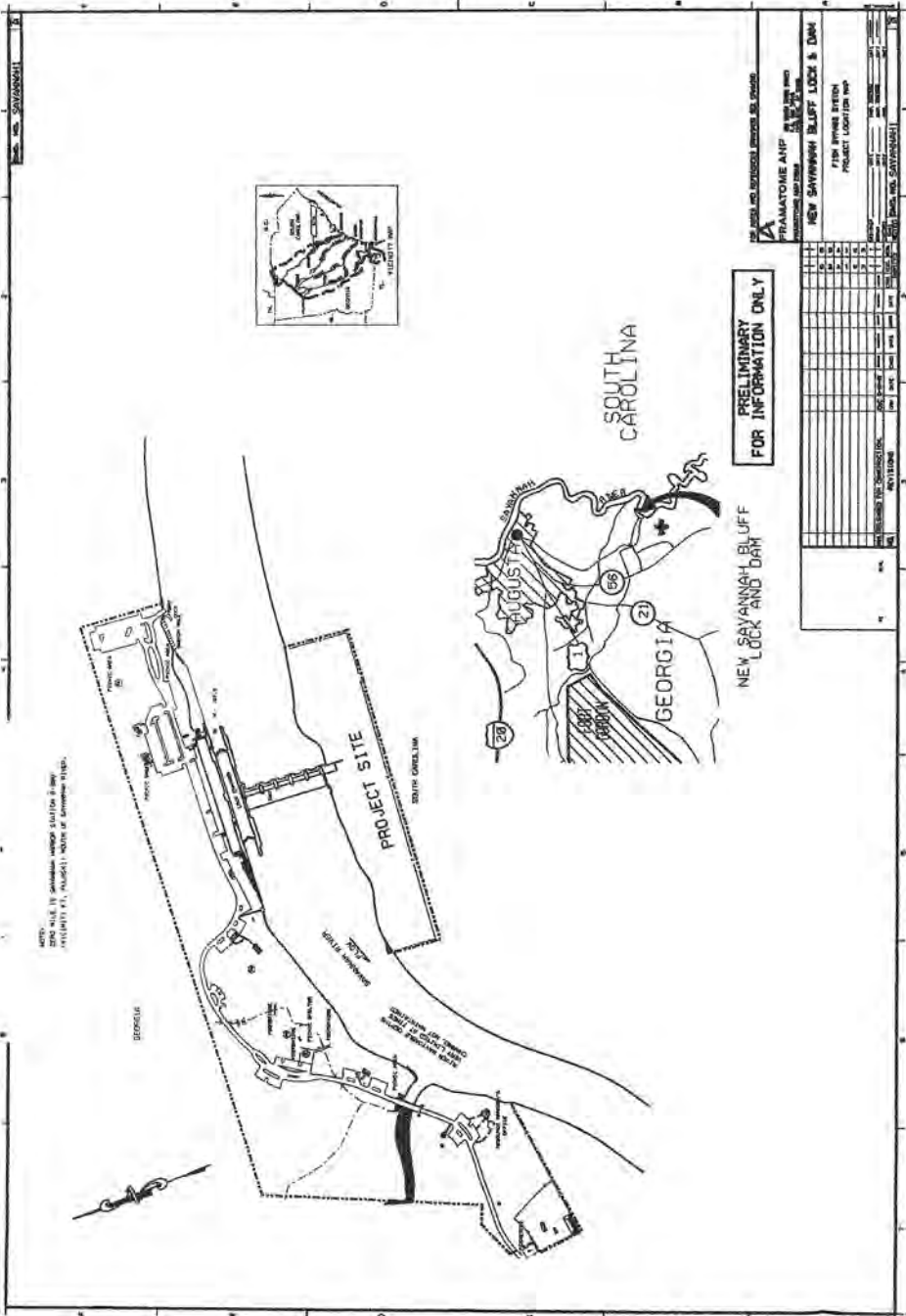
- Abt, S.R., J.F. Ruff, R.J. Wittler. 1991. Estimating Flow through riprap. *ASCE Journal of Hydraulic Engineering* 117:670-675, 1991.
- Beamish, F.W.H., R.S. McKinley, D.A. Scruton, C. Katopodis. 1996. Relating swimming performance of lake sturgeon, *Acipenser fulvescens*, to fishway design. *Can. J. Fish. Aquat. Sci.* 54:1361-1366, 1997.
- Bell, Milo. 1986. *Fisheries Handbook of Engineering Requirements and Biological Criteria*. 2<sup>nd</sup> Edition. Corps of Engineers, Portland, Oregon.
- Brater, E. F., H. W. King. 1976. *Handbook of hydraulics for the solution of hydraulic engineering problems*. 6<sup>th</sup> Edition. McGraw-Hill, Inc., NY.
- Clay, Charles H. 1995. *Design of fishways and other fish facilities*. 2<sup>nd</sup> Edition. CRC Press, Boca Raton, Florida.
- Framatome ANP DE&S (FANP DE&S). 2002. *New Savannah Bluff Lock & Dam Project, Savannah River Georgia and South Carolina, Fish Passage Report*. Prepared for U. S. Army Corps of Engineers, Mobile AL, August 2002.
- Haro, A., B. Kynard. 1997. Video evaluation of passage efficiency of American shad and sea lamprey in a modified ice harbor fishway. *North American Journal of Fisheries Management* 17:981-987, 1997.
- Kells, J.A., M. Acharya, C. Katopodis. 2000. Design of nature-like fishways for small dam projects. *Proceedings, 3<sup>rd</sup> Annual Conference, Canadian Dam Association*.
- Kynard, B. 1998. Twenty-two years of passing shortnose sturgeon in fish lifts on the Connecticut River: What has been learned?. *Fish Migration and Fish Bypasses*. Blackwell Science Ltd., Malden, MA.
- Linsley, R.K., M. Kohler, J.L.H. Paulhus. *Hydrology for Engineers*. McGraw-Hill Book Company, Inc. 1958.
- Maynard, S.T. 1991. Flow resistance of riprap. *ACSE Journal of Hydraulic Engineering* 117:687-695, 1991.
- Mefford, B. 2002. Designing combination structures, notes. *Engineering Innovative Fish Passage: Dam Removal and Nature-like Fishways*. NH Dept of Environmental Services, Waterville Valley, NH.
- Monk, B., D. Weaver, C. Thompson, F. Osslander. 1989. Effects of flow and weir design on the passage behavior of American shad and salmonids in an experimental fish ladder. *North American Journal of Fisheries Management* 9:60-67, 1989.

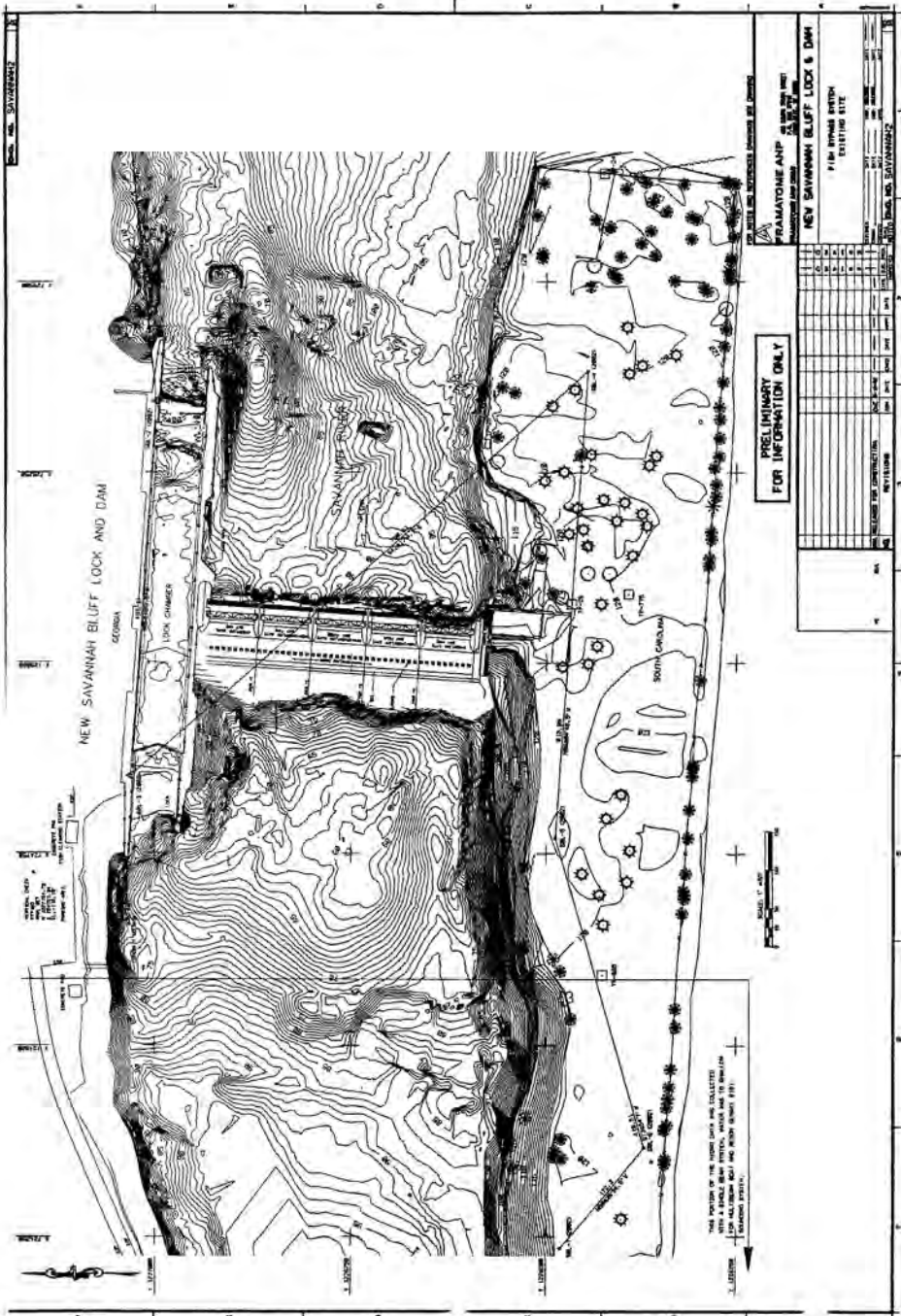


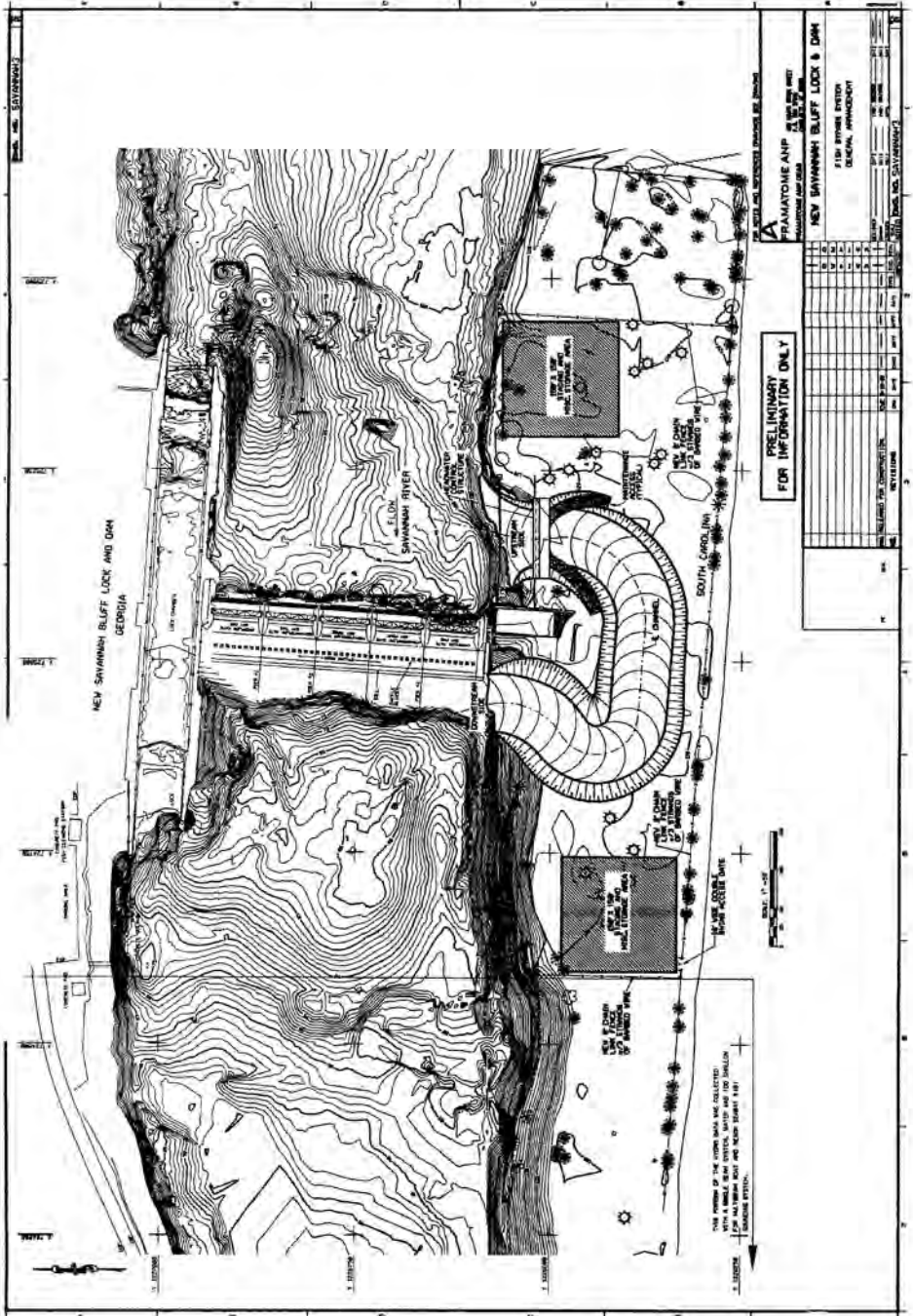
- Moser, M., A. M. Darazsdi, J. R. Hall. 1999. Improving passage efficiency of adult American shad at low-elevation dams with navigation locks. *North American Journal of Fisheries Management* 20:376-385, 2000.
- Painter, R.E., L. H. Wixom. Striped bass fishway and swimming endurance tests. Sixth Annual Report, California Department of Water Resources.
- Parasiewicz, P. J. Eberstaller, S. Weiss, S. Schmutz. 1998. Conceptual guidelines for nature-like bypass channels. *Fish Migration and Fish Bypasses*. Blackwell Science Ltd., Malden, MA.
- Scheidegger, K. 2002. Fish gotta swim. *Wisconsin Natural Resources Magazine*. Wisconsin Department of Natural Resources.
- State of Alaska, Hydraulics Manual, State of Alaska Department of Highways.
- Washington Sea Grant Program. Fishway use by white sturgeon on the Columbia River. Washington Sea Grant Program, Seattle, WA.
- Weaver, C., C.S. Thompson, E. Slatick. 1969. Effect of weir configuration on fish passage. Fourth Progress Report on Fisheries Engineering Research Program 1966-1972. US Army Corps of Engineers. May 1976.
- Wittler, R.J. 1996. Features of a chevron weir rock ramp. North American Water and Environment Congress. American Society of Civil Engineers.

**Appendices**

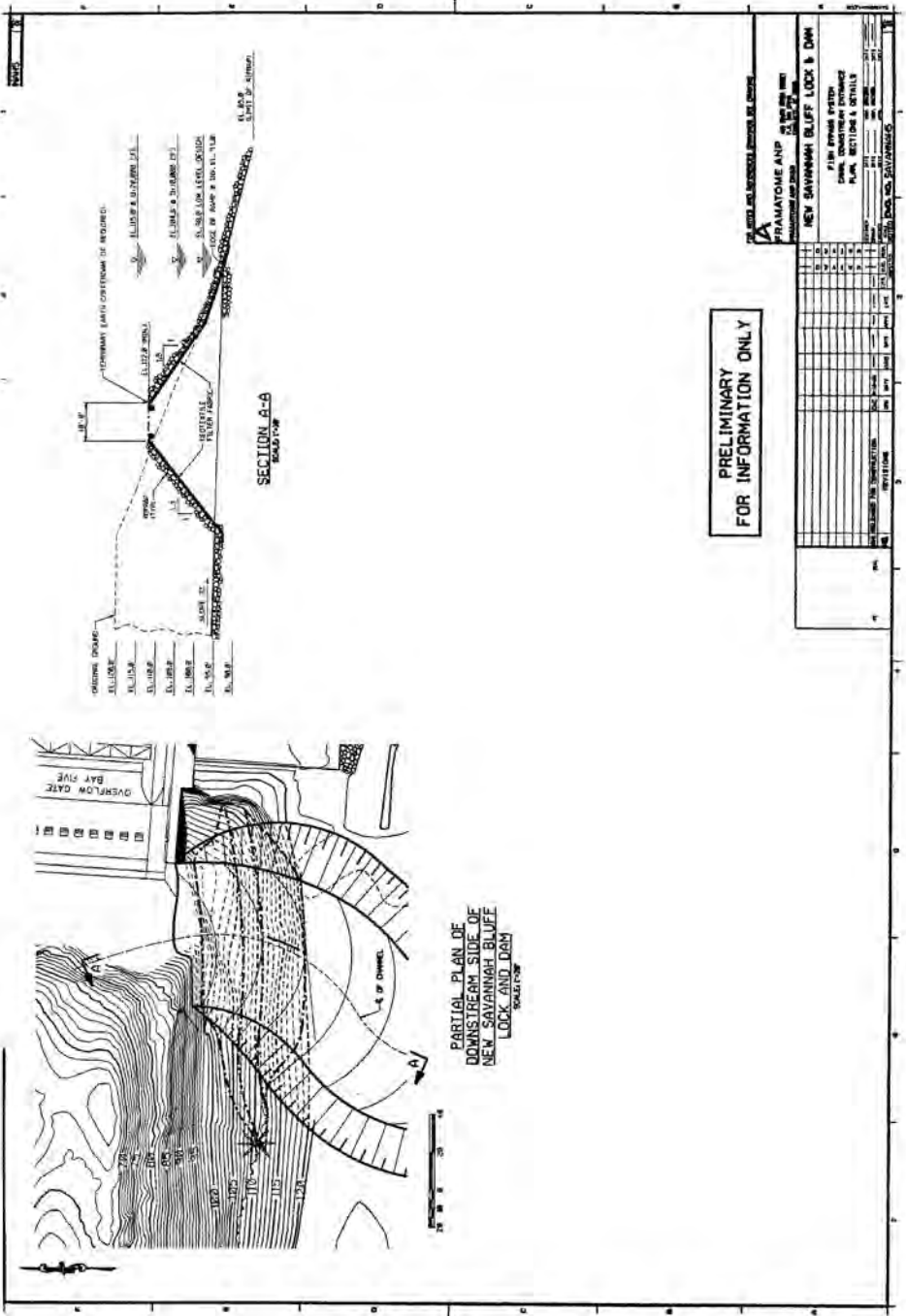
**Appendix A - Drawings**



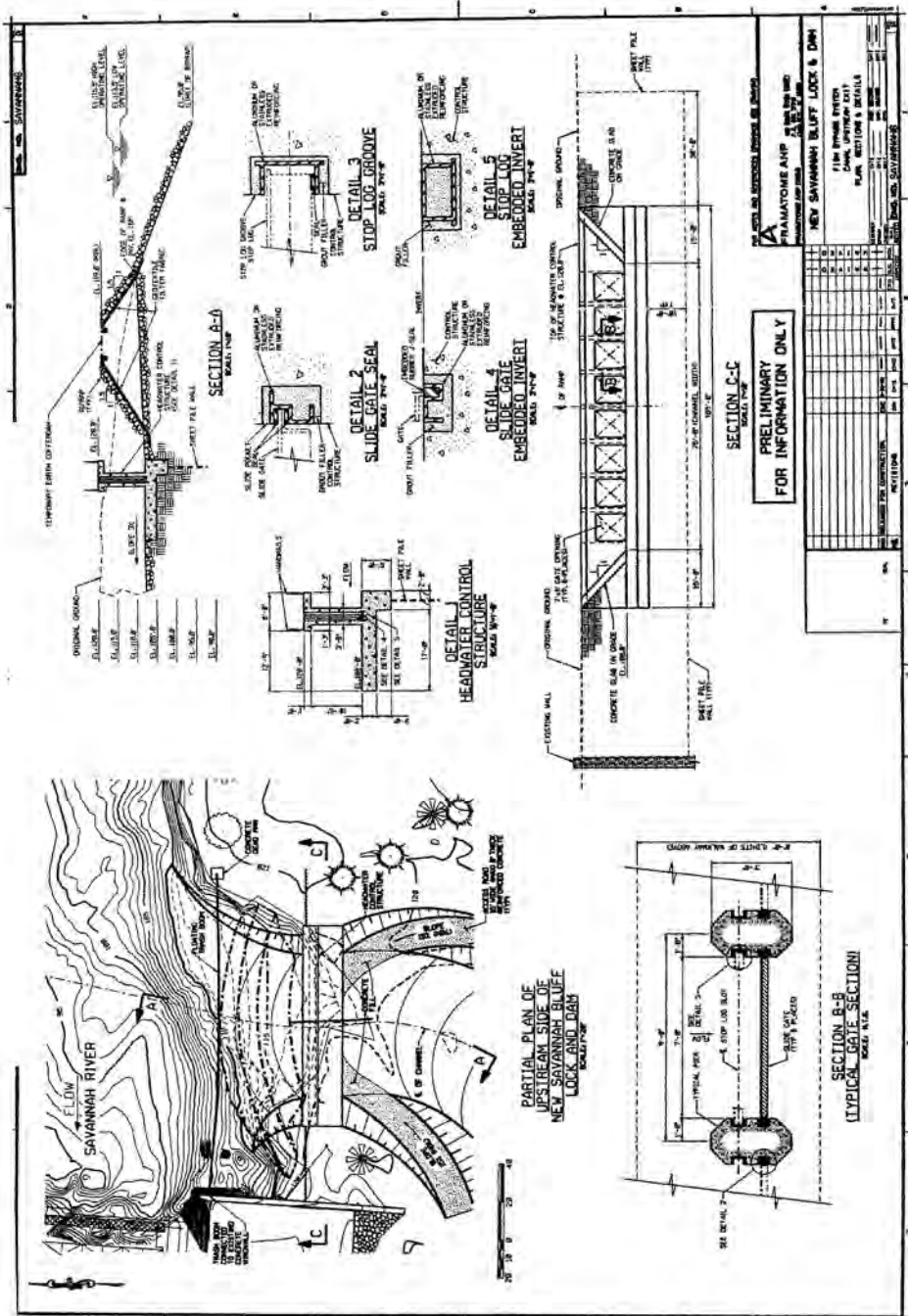




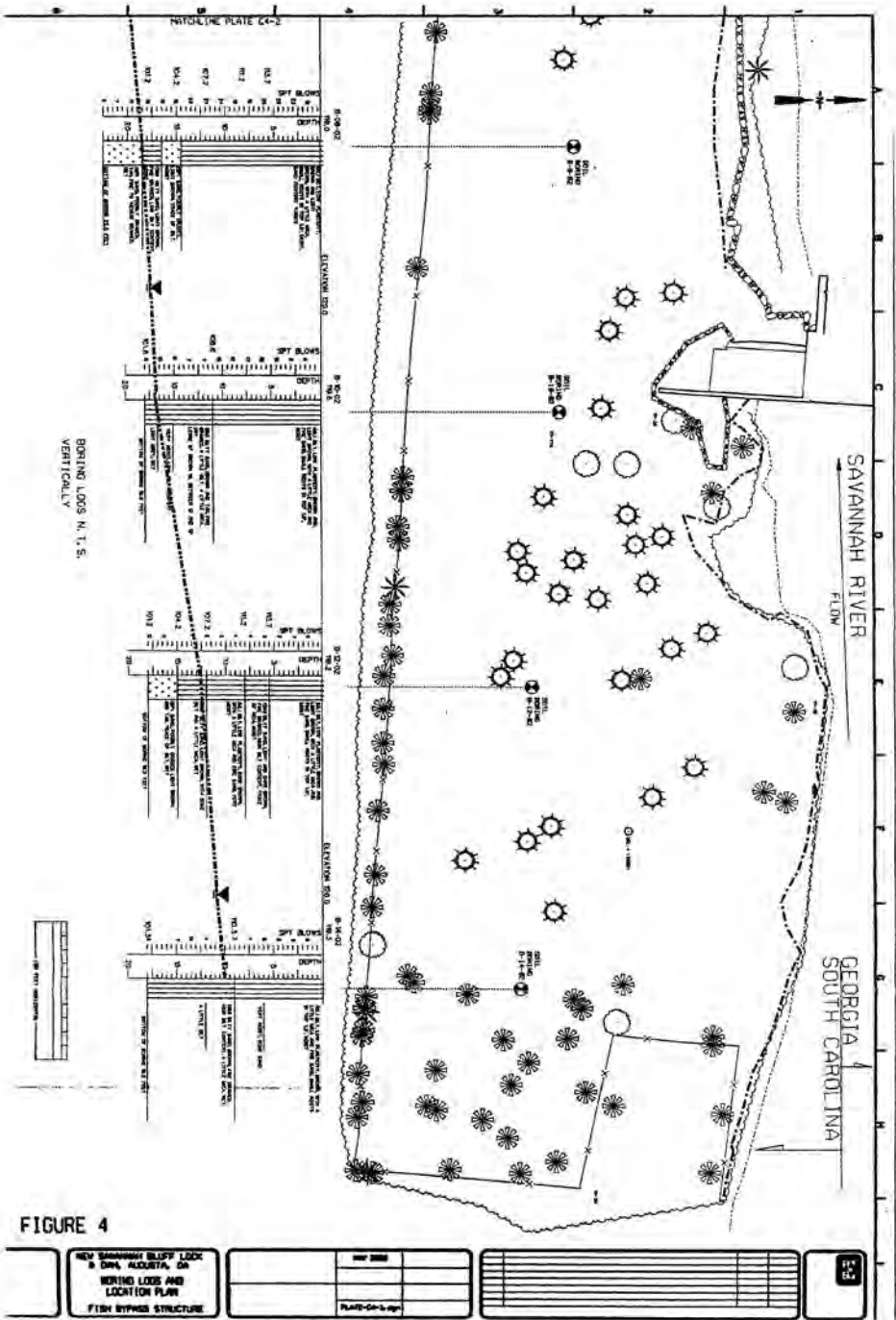








**Appendix B - Boring Logs**



GEORGIA  
SOUTH CAROLINA

SAVANNAH RIVER

FLOW

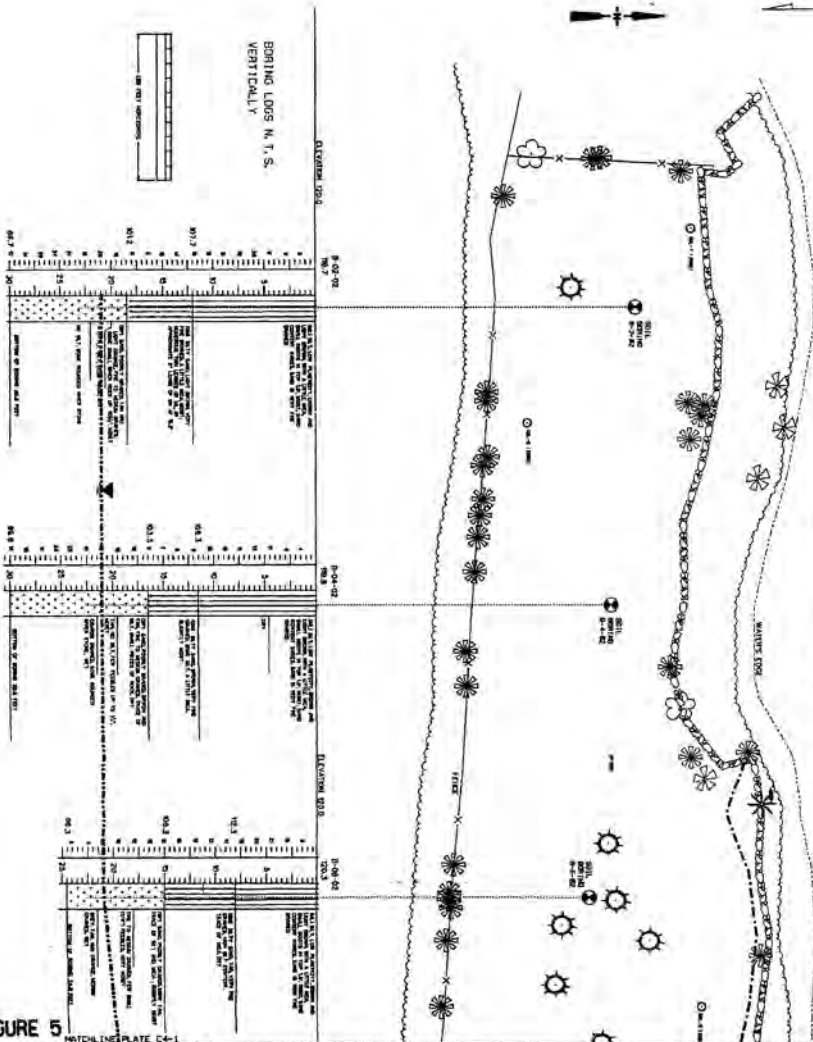
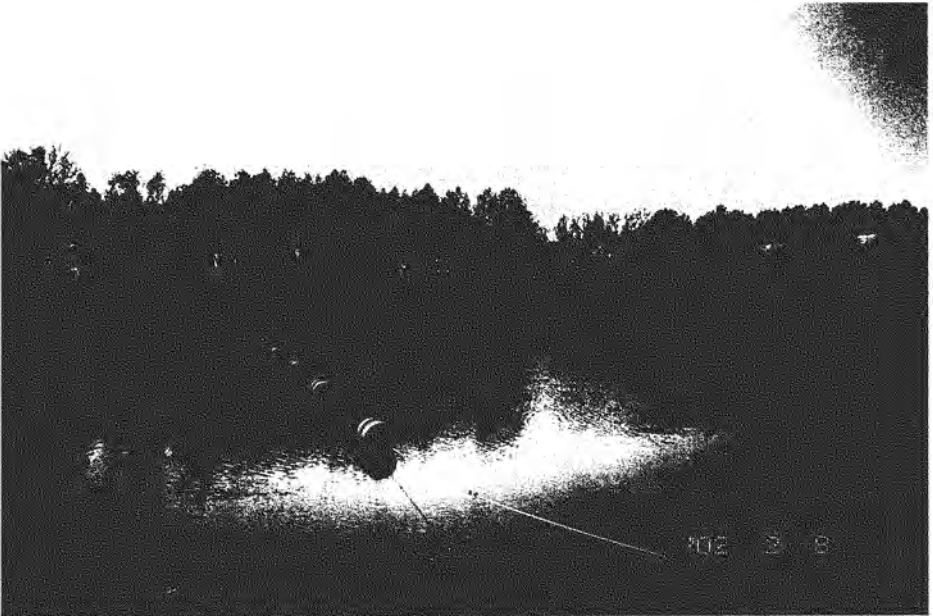


FIGURE 5

NEW SAVANNAH BLUFF LOCK & DAM, AUGUSTA, GA  
BRIDGE LOCK AND  
LOCATION PLAN  
FROM BRIDGE STRUCTURE

|         |               |
|---------|---------------|
| NO. 100 | PLATE 100-1   |
| NO. 101 | PLATE 100-2   |
| NO. 102 | PLATE 100-3   |
| NO. 103 | PLATE 100-4   |
| NO. 104 | PLATE 100-5   |
| NO. 105 | PLATE 100-6   |
| NO. 106 | PLATE 100-7   |
| NO. 107 | PLATE 100-8   |
| NO. 108 | PLATE 100-9   |
| NO. 109 | PLATE 100-10  |
| NO. 110 | PLATE 100-11  |
| NO. 111 | PLATE 100-12  |
| NO. 112 | PLATE 100-13  |
| NO. 113 | PLATE 100-14  |
| NO. 114 | PLATE 100-15  |
| NO. 115 | PLATE 100-16  |
| NO. 116 | PLATE 100-17  |
| NO. 117 | PLATE 100-18  |
| NO. 118 | PLATE 100-19  |
| NO. 119 | PLATE 100-20  |
| NO. 120 | PLATE 100-21  |
| NO. 121 | PLATE 100-22  |
| NO. 122 | PLATE 100-23  |
| NO. 123 | PLATE 100-24  |
| NO. 124 | PLATE 100-25  |
| NO. 125 | PLATE 100-26  |
| NO. 126 | PLATE 100-27  |
| NO. 127 | PLATE 100-28  |
| NO. 128 | PLATE 100-29  |
| NO. 129 | PLATE 100-30  |
| NO. 130 | PLATE 100-31  |
| NO. 131 | PLATE 100-32  |
| NO. 132 | PLATE 100-33  |
| NO. 133 | PLATE 100-34  |
| NO. 134 | PLATE 100-35  |
| NO. 135 | PLATE 100-36  |
| NO. 136 | PLATE 100-37  |
| NO. 137 | PLATE 100-38  |
| NO. 138 | PLATE 100-39  |
| NO. 139 | PLATE 100-40  |
| NO. 140 | PLATE 100-41  |
| NO. 141 | PLATE 100-42  |
| NO. 142 | PLATE 100-43  |
| NO. 143 | PLATE 100-44  |
| NO. 144 | PLATE 100-45  |
| NO. 145 | PLATE 100-46  |
| NO. 146 | PLATE 100-47  |
| NO. 147 | PLATE 100-48  |
| NO. 148 | PLATE 100-49  |
| NO. 149 | PLATE 100-50  |
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| NO. 188 | PLATE 100-89  |
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| NO. 192 | PLATE 100-93  |
| NO. 193 | PLATE 100-94  |
| NO. 194 | PLATE 100-95  |
| NO. 195 | PLATE 100-96  |
| NO. 196 | PLATE 100-97  |
| NO. 197 | PLATE 100-98  |
| NO. 198 | PLATE 100-99  |
| NO. 199 | PLATE 100-100 |

## **Appendix C - Site Photographs**



**Photo 1 – Distant view of left  
abutment upstream of Dam**



**Photo 2 - View of left  
abutment just  
upstream of Dam**



Photo 3 – View of left abutment just upstream of Dam



Photo 4 – View of left abutment just upstream of Dam



**Photo 5 – View of left abutment area from Dam Structure**



**Photo 6 – View of left abutment area**

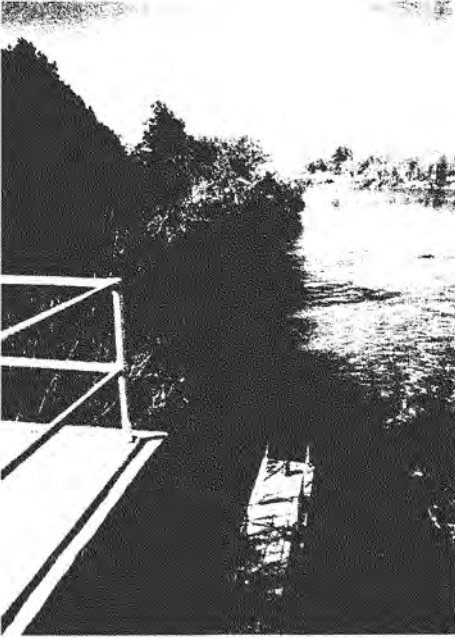




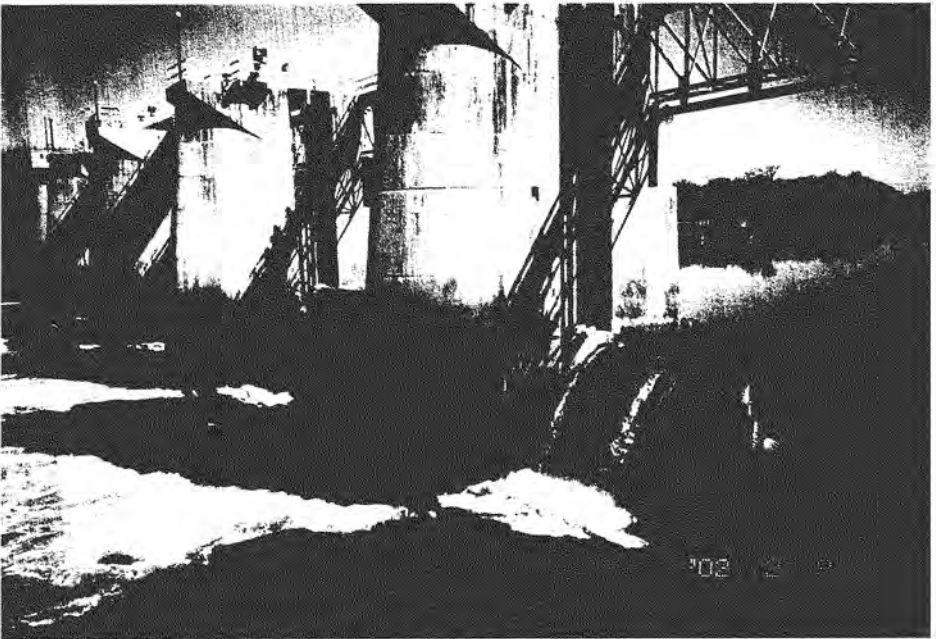
**Photo 7 – View of left abutment area just downstream of Dam**



**Photo 8 – View of left abutment area downstream of Dam**



**Photo 9 – View of left  
abutment area  
downstream of Dam**



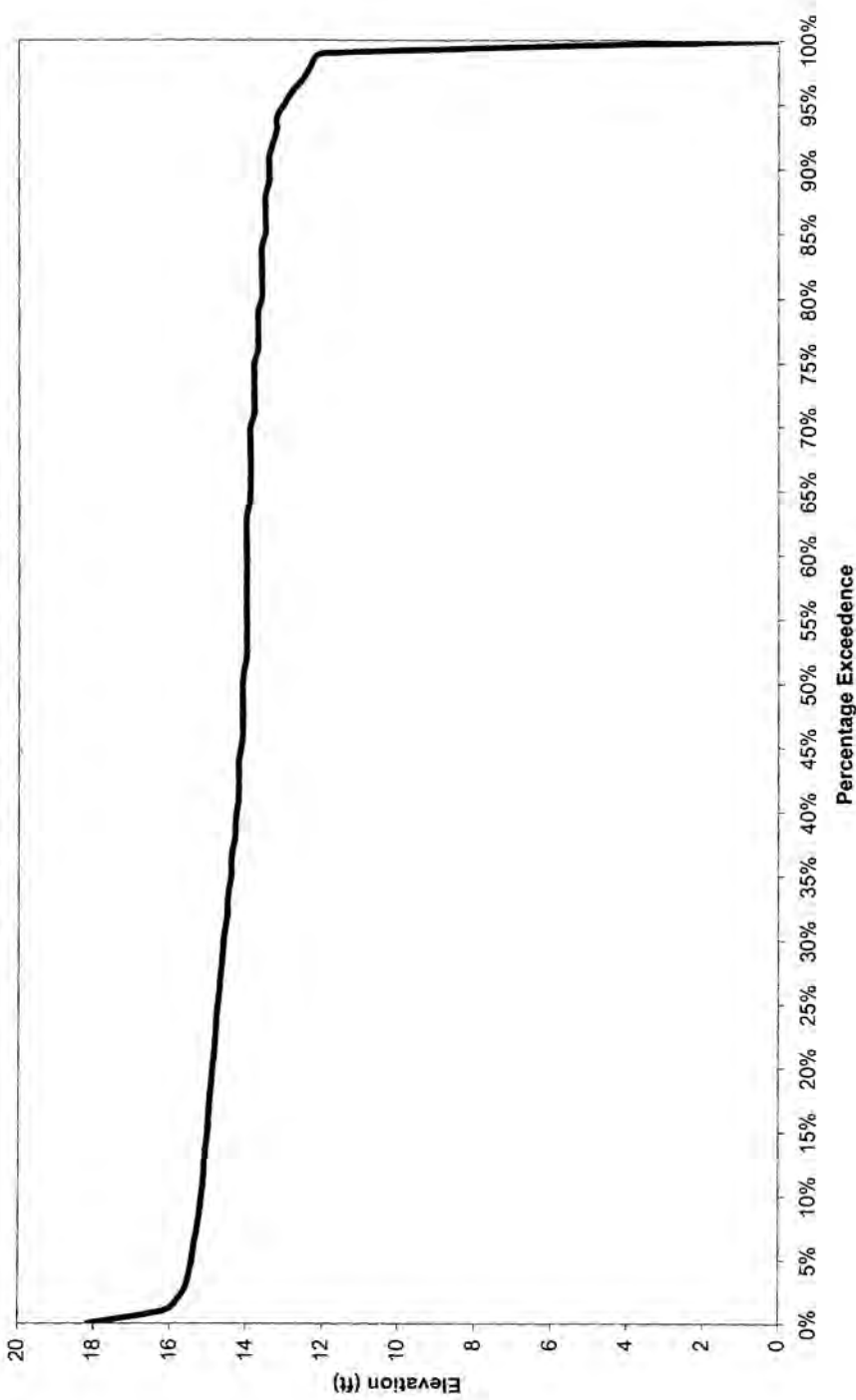
**Photo 10 – View of Spillway Gate No. 5 near turn**

**Appendix D - Material Quantity Estimates**

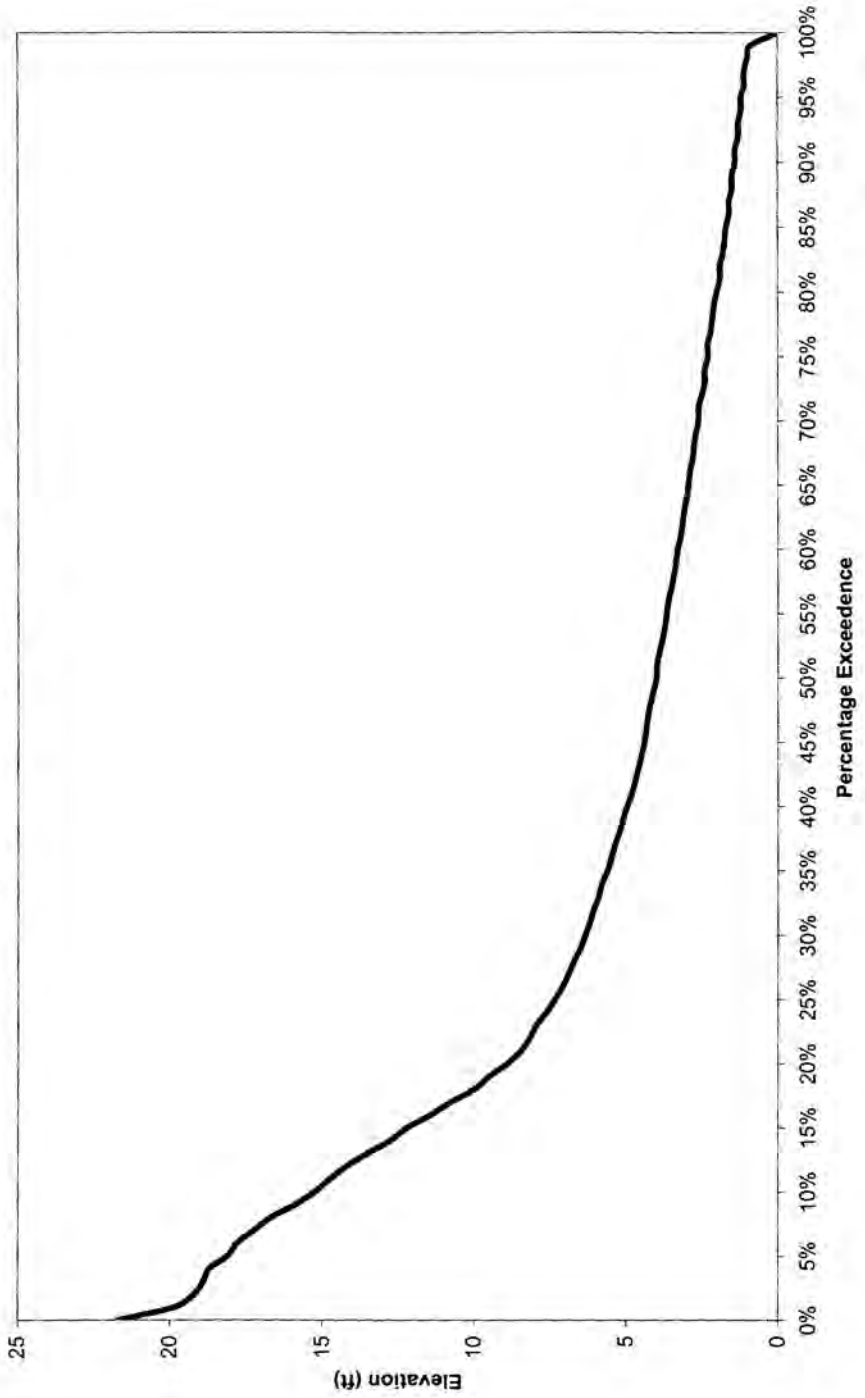
**This Section Intentionally Left Blank  
See Section VI for Material Quantity Estimate**

**Appendix E – Hydrology****Note:****Headwater Gauge Datum = 100.58 (NGVD)****Tailwater Gauge Datum = 96.58 (NGVD)**

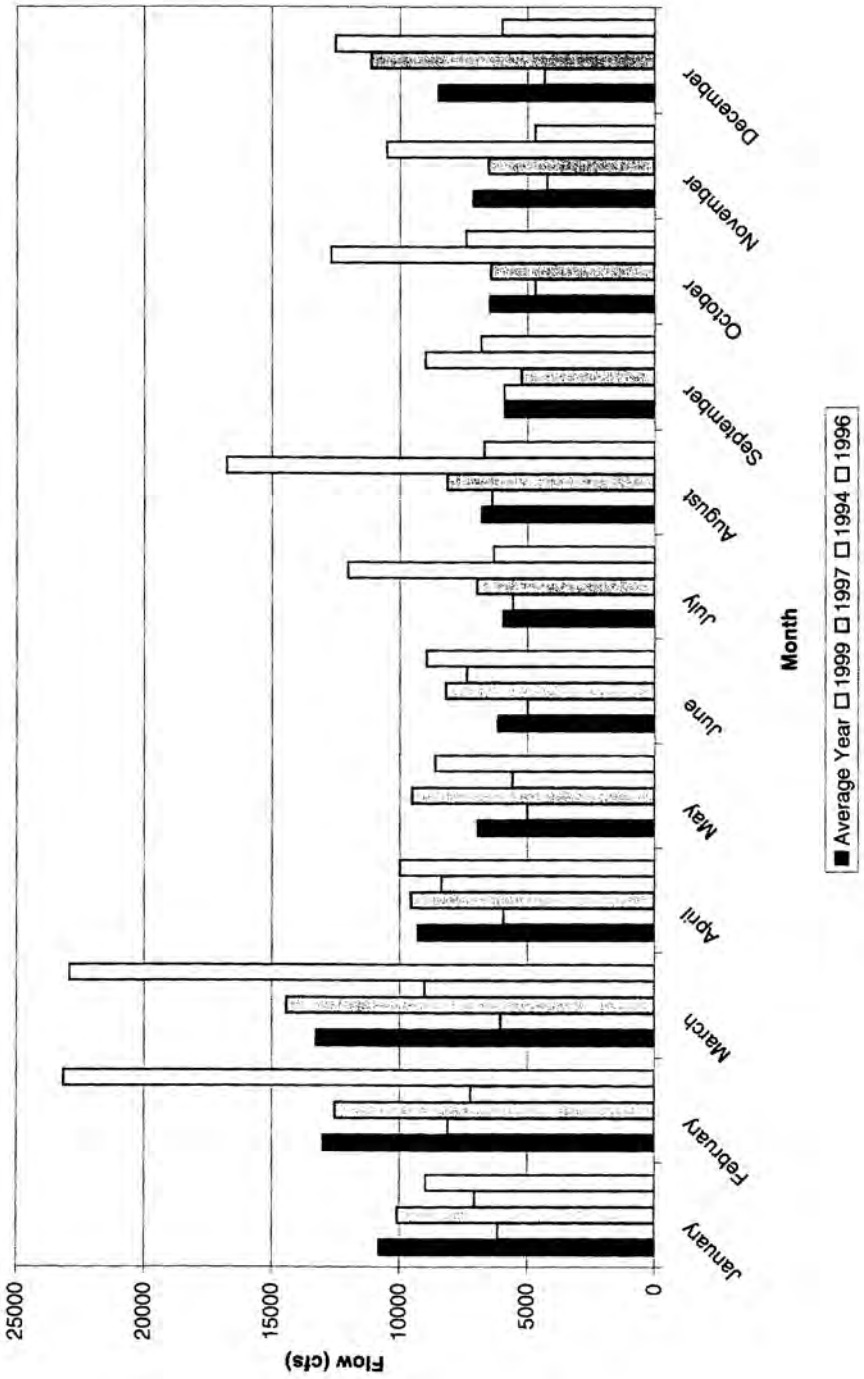
Upper Pool Duration Curve  
Butler Creek Upper Pool (08:00) 1/1/1992 - 4/2/2002



**Tailwater Duration Curve**  
Butler Creek Tail Water (08:00) 1/1/1992 - 4/2/2002

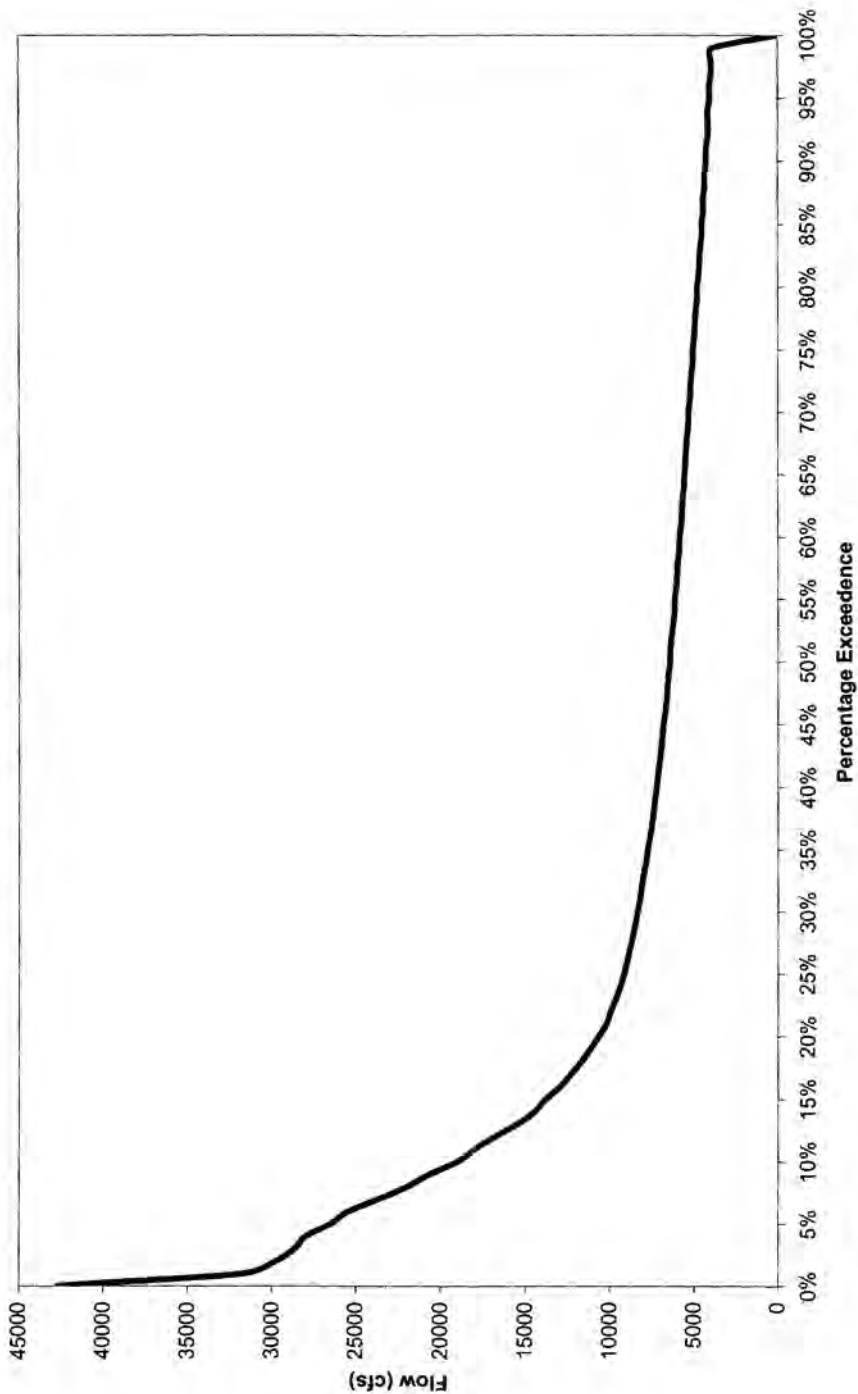


## Average Year Flows



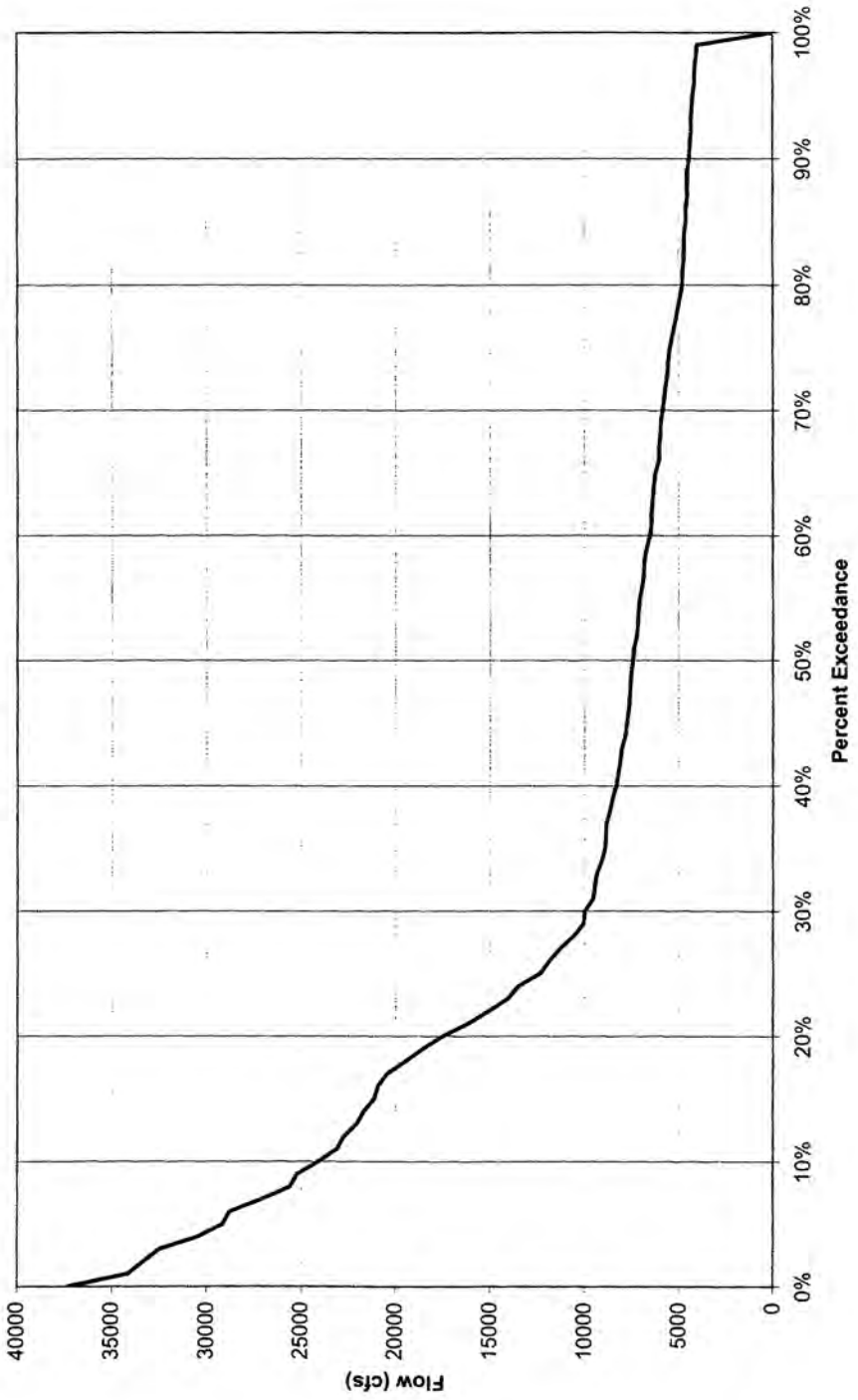
**Butler Creek Discharge Duration Curve**

Butler Creek Discharge 1/1/1992 - 4/2/2002

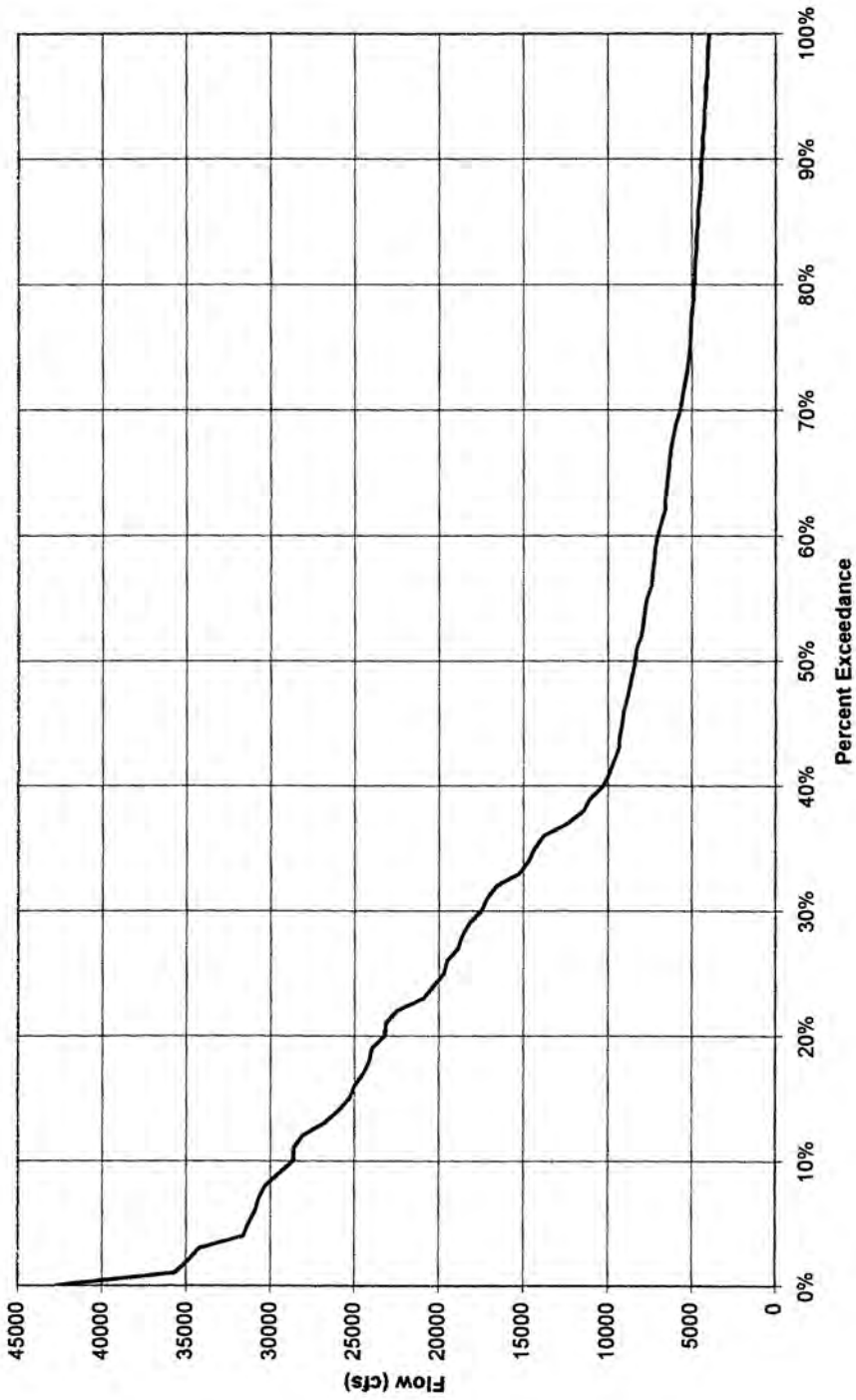




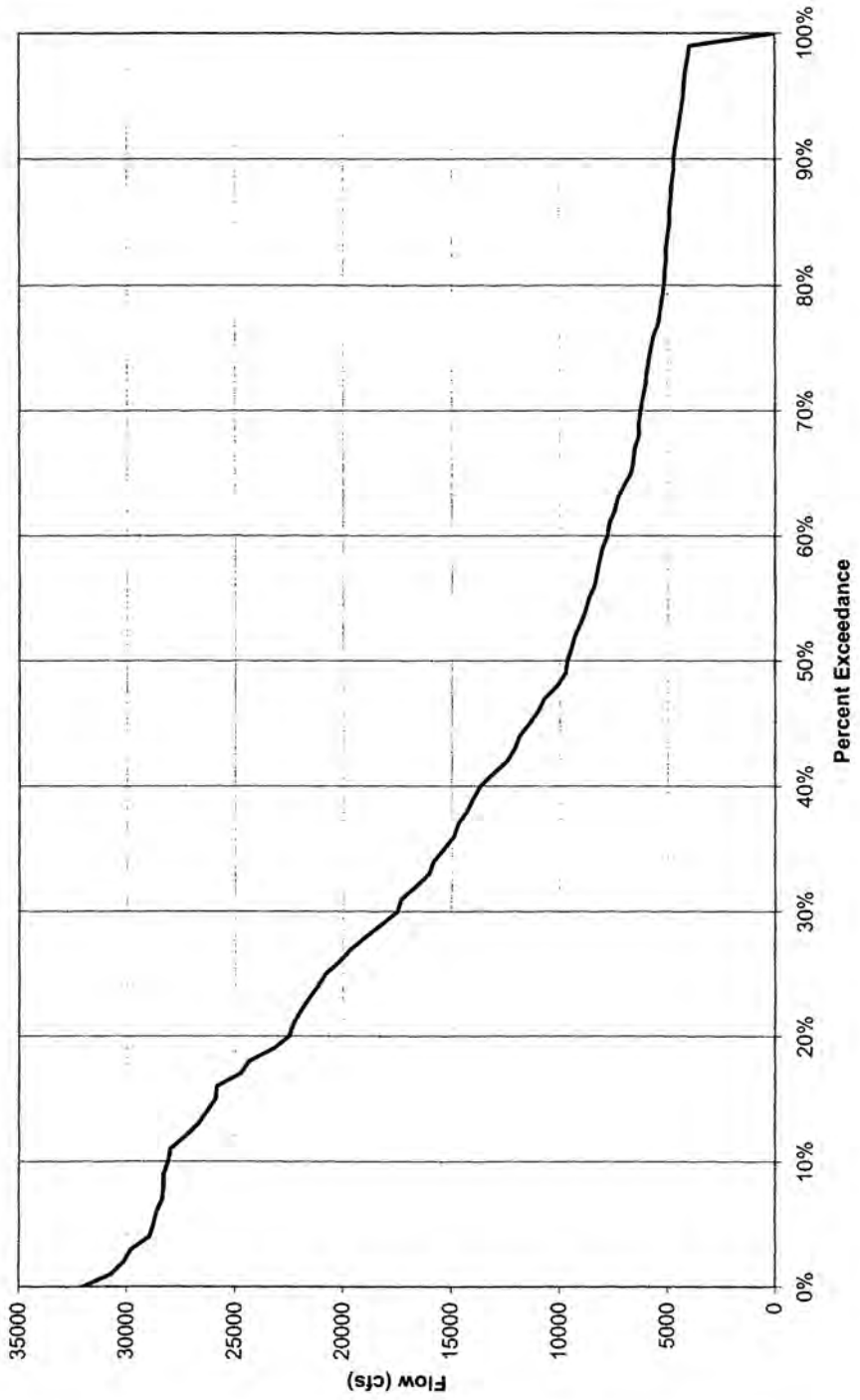
Butler Creek January Flow Duration Curve  
1/1/1992 - 4/2/2002



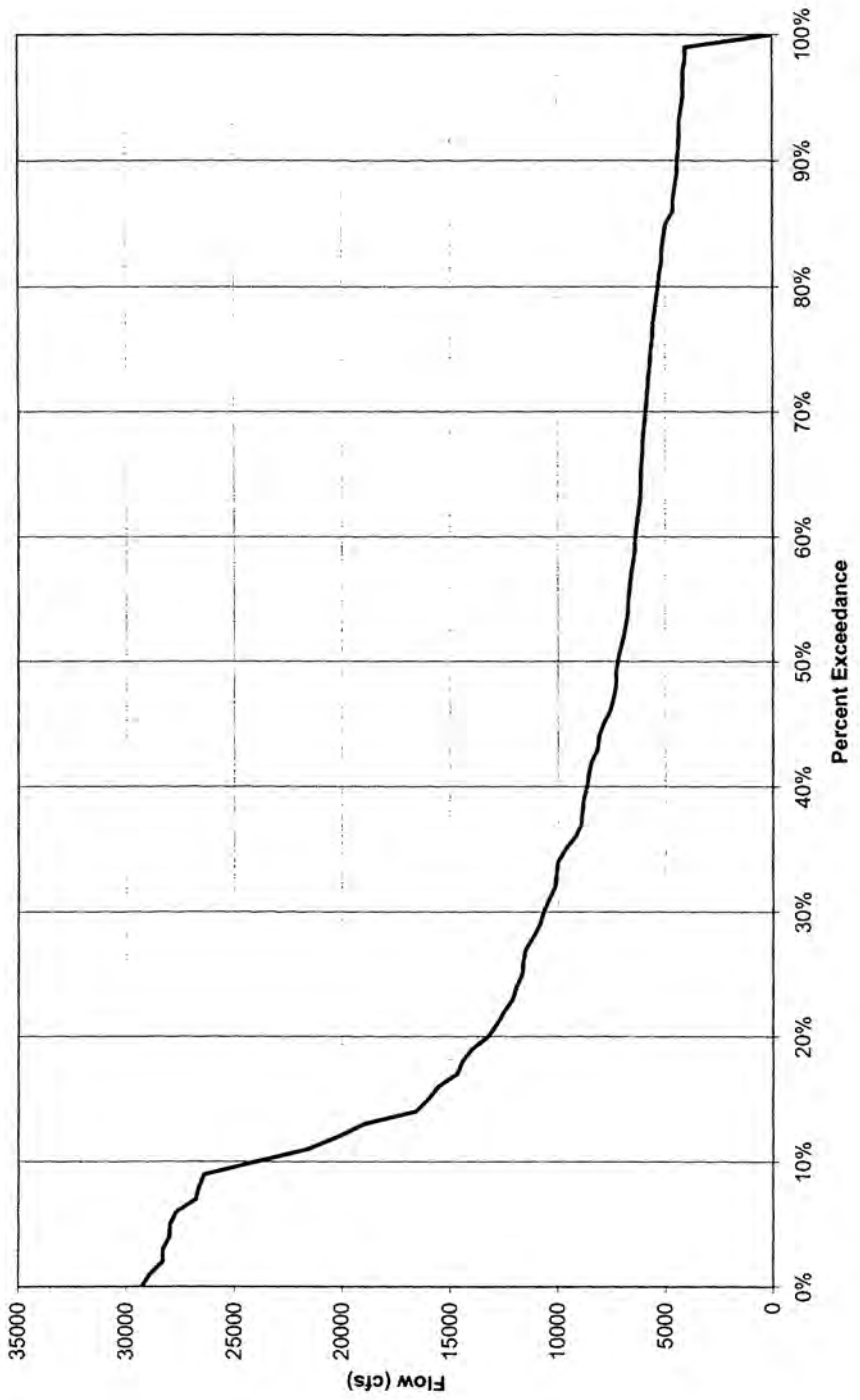
Butler Creek February Flow Duration Curve  
1/1/1992 - 4/2/2002



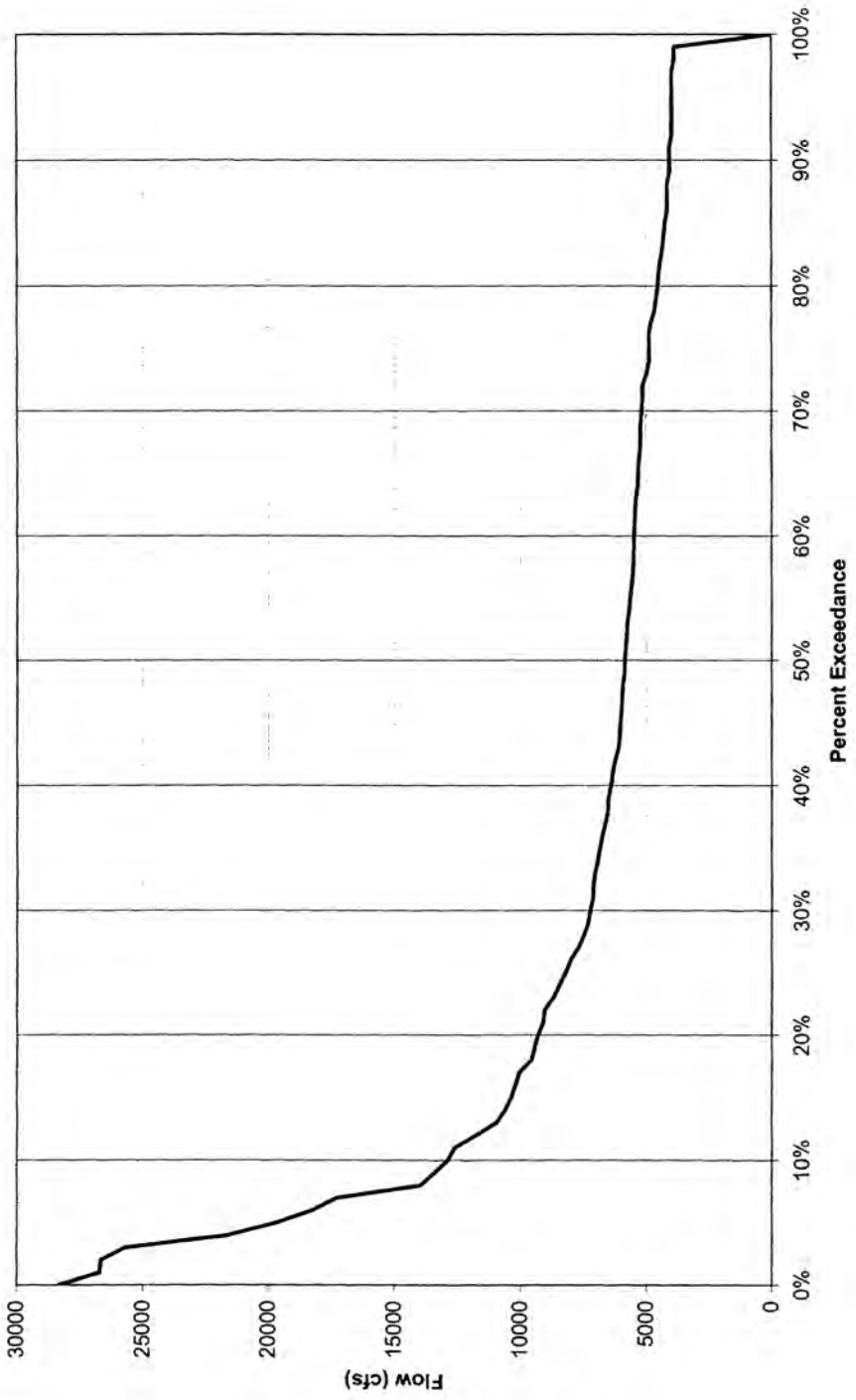
Butler Creek March Flow Duration Curve  
1/1/1992 - 4/2/2002



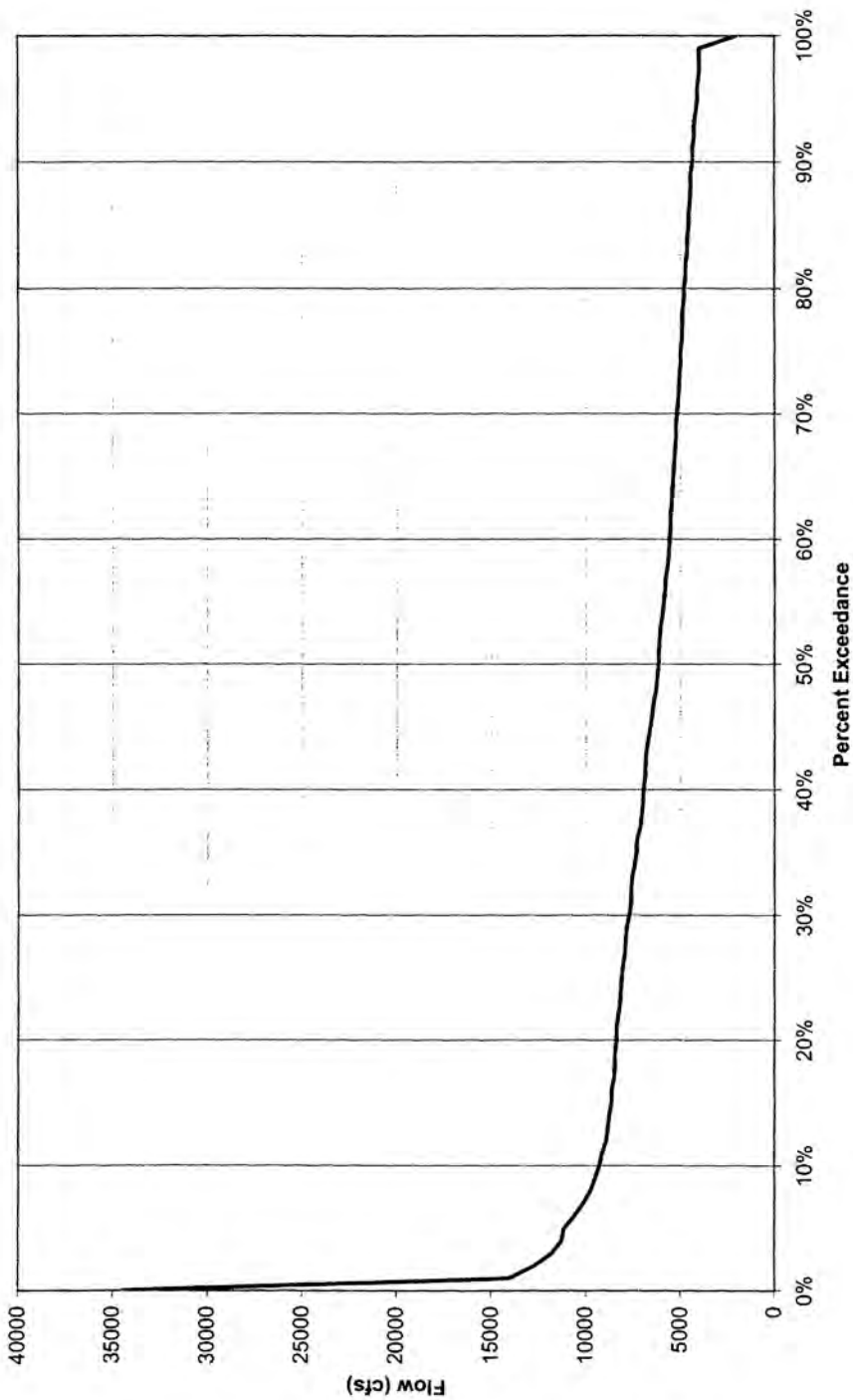
Butler Creek April Flow Duration Curve  
1/1/1992 - 4/2/2002



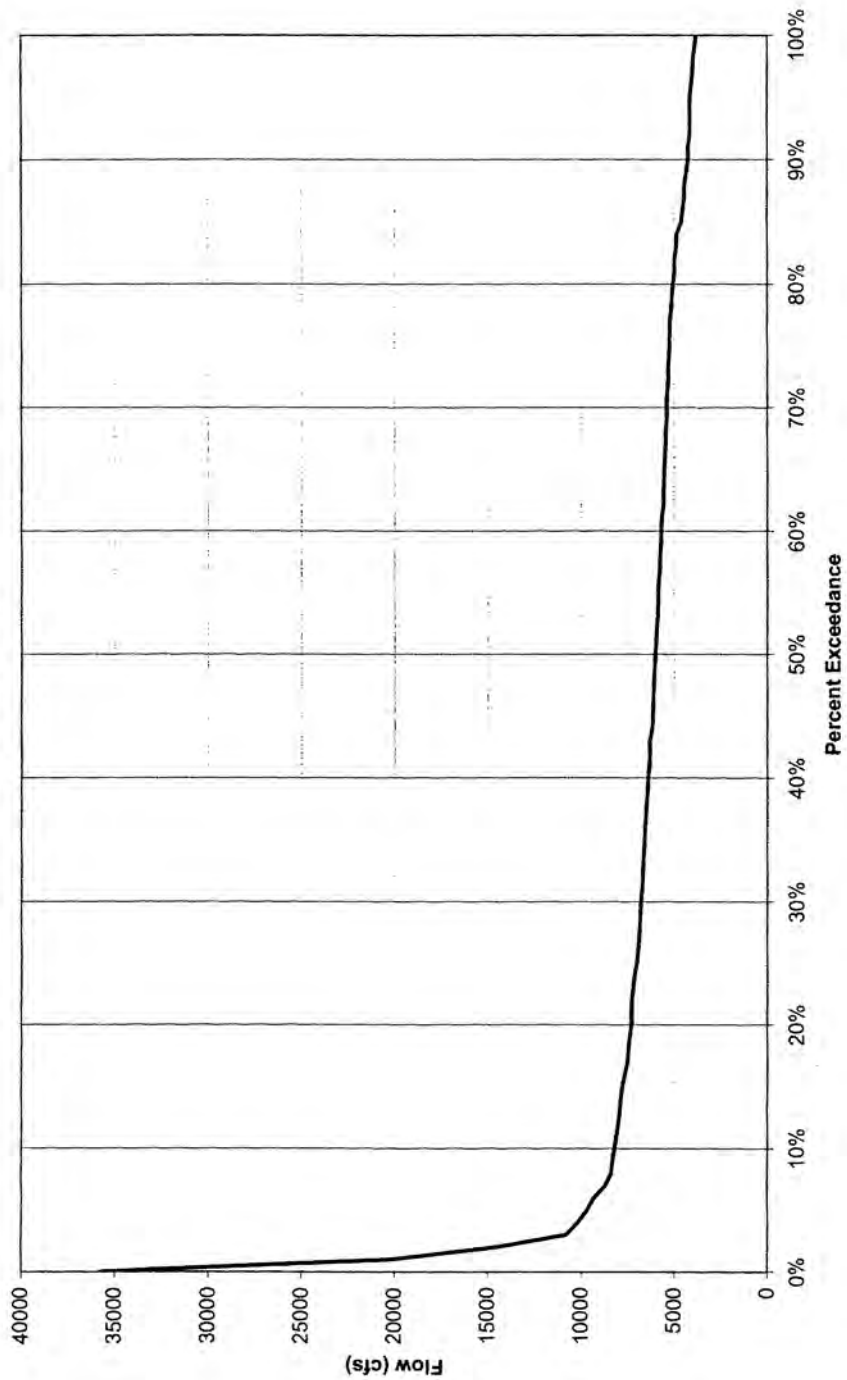
Butler Creek May Flow Duration Curve  
1/1/1992 - 4/2/2002



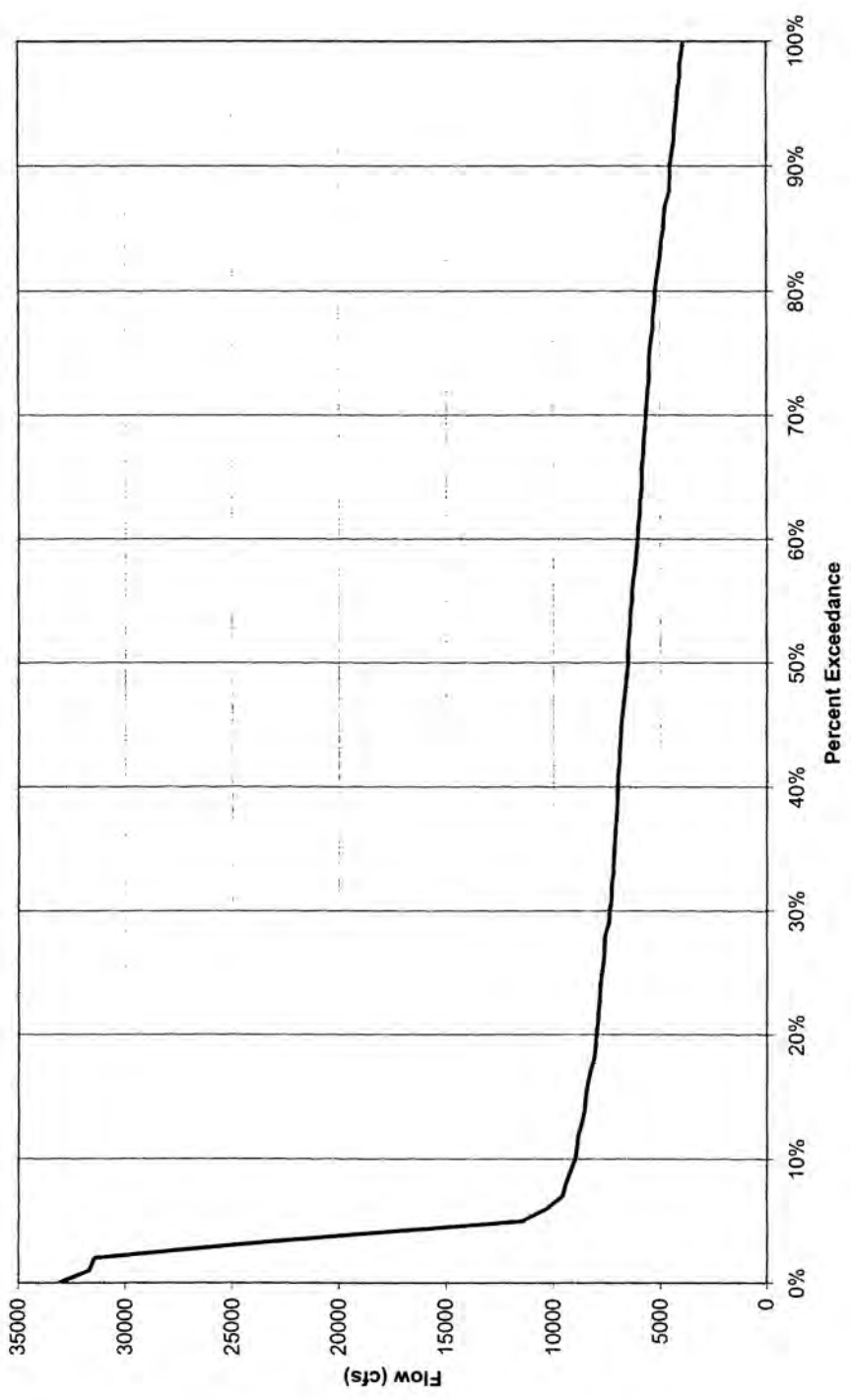
Butler Creek June Flow Duration Curve  
1/1/1992 - 4/2/2002



Butler Creek July Flow Duration Curve  
1/1/1992 - 4/2/2002

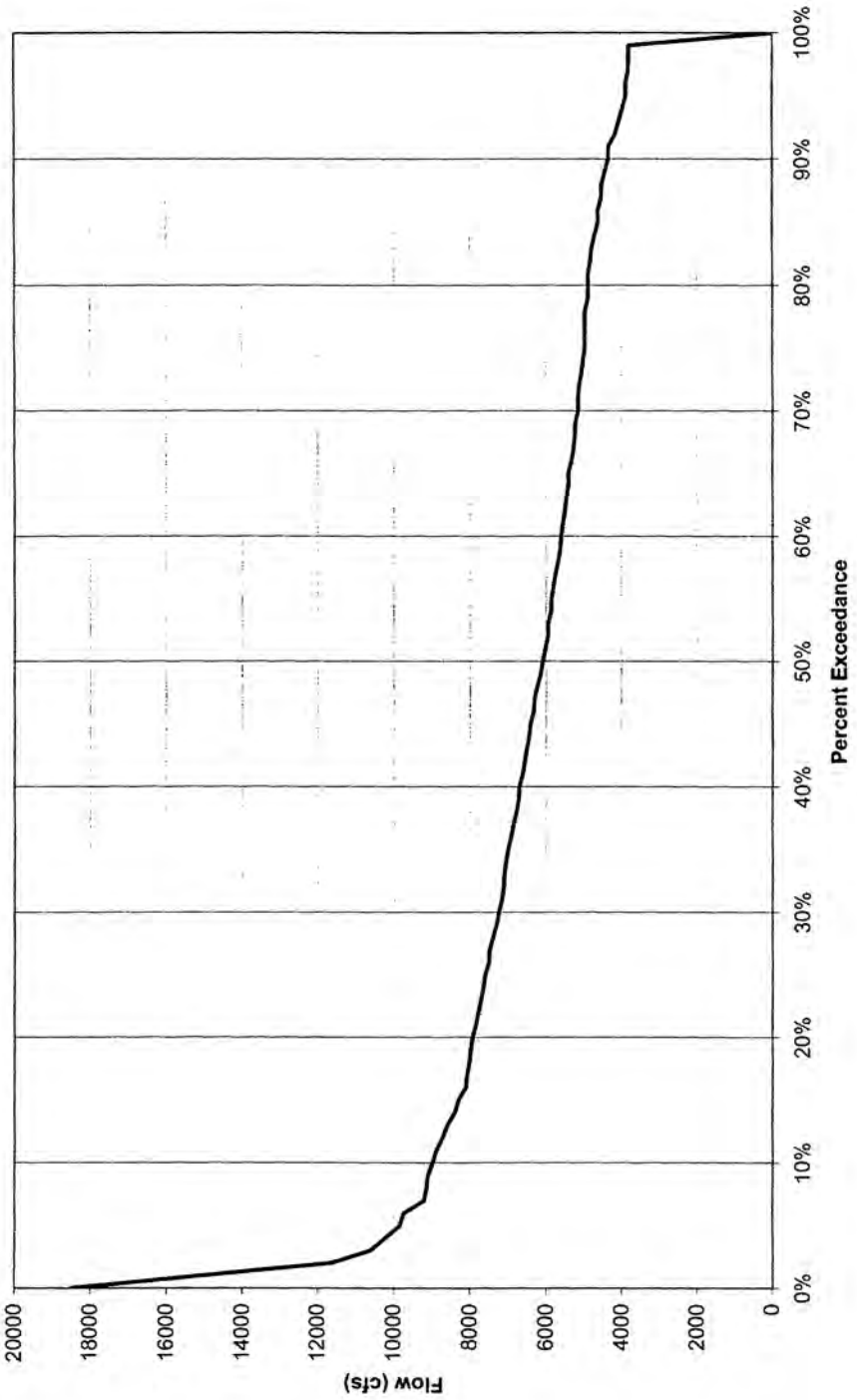


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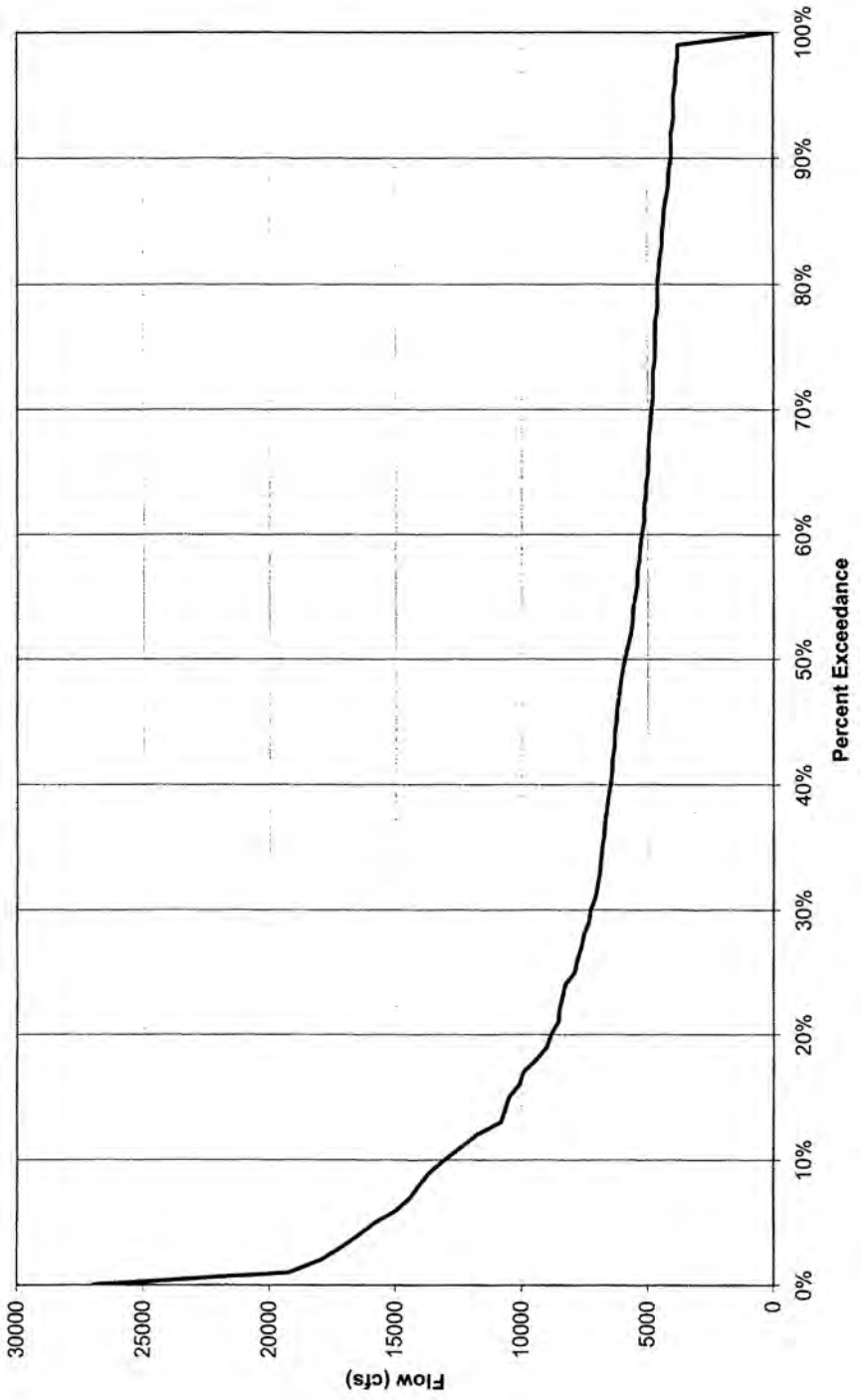




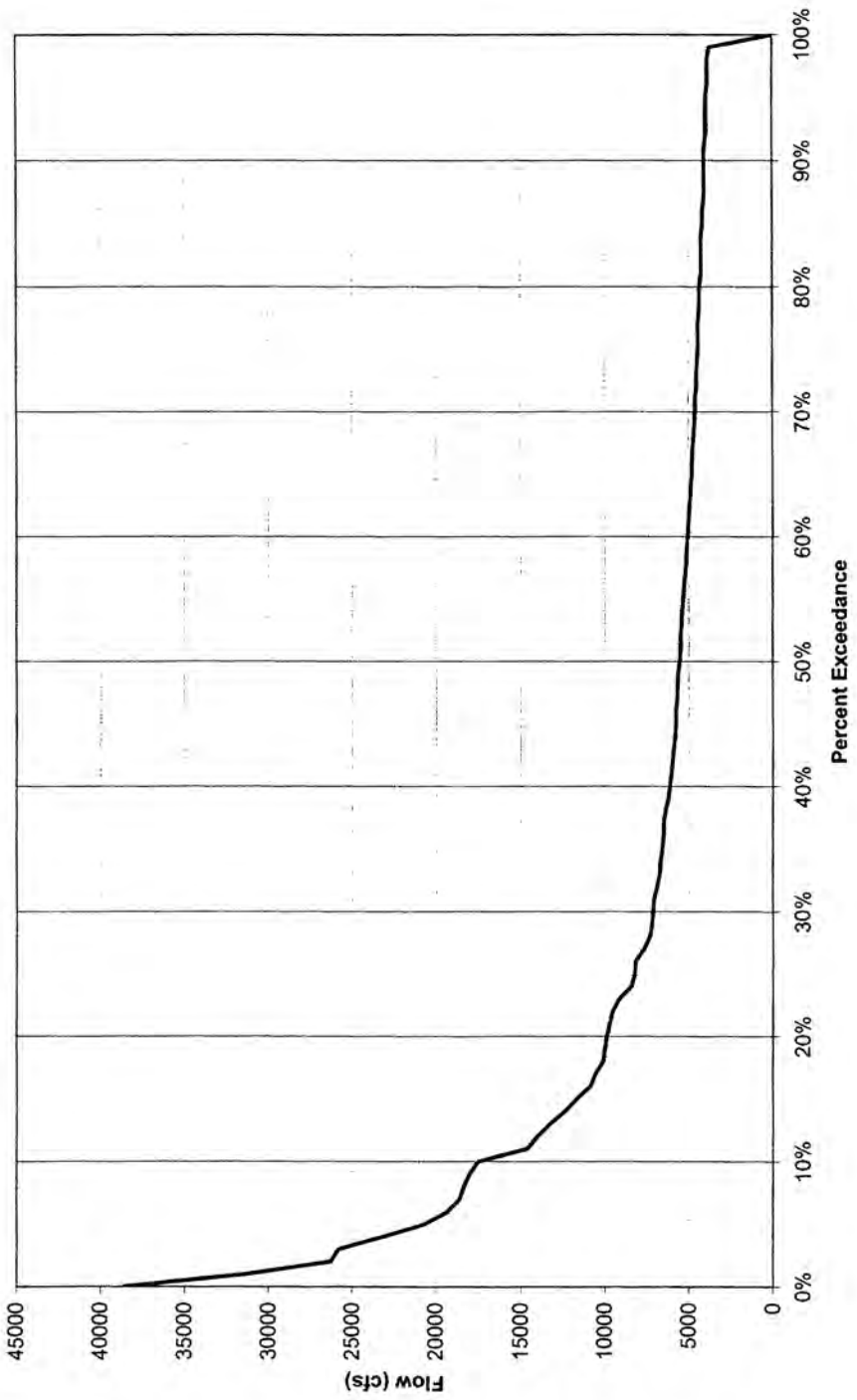
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1/1/1992 - 4/2/2002



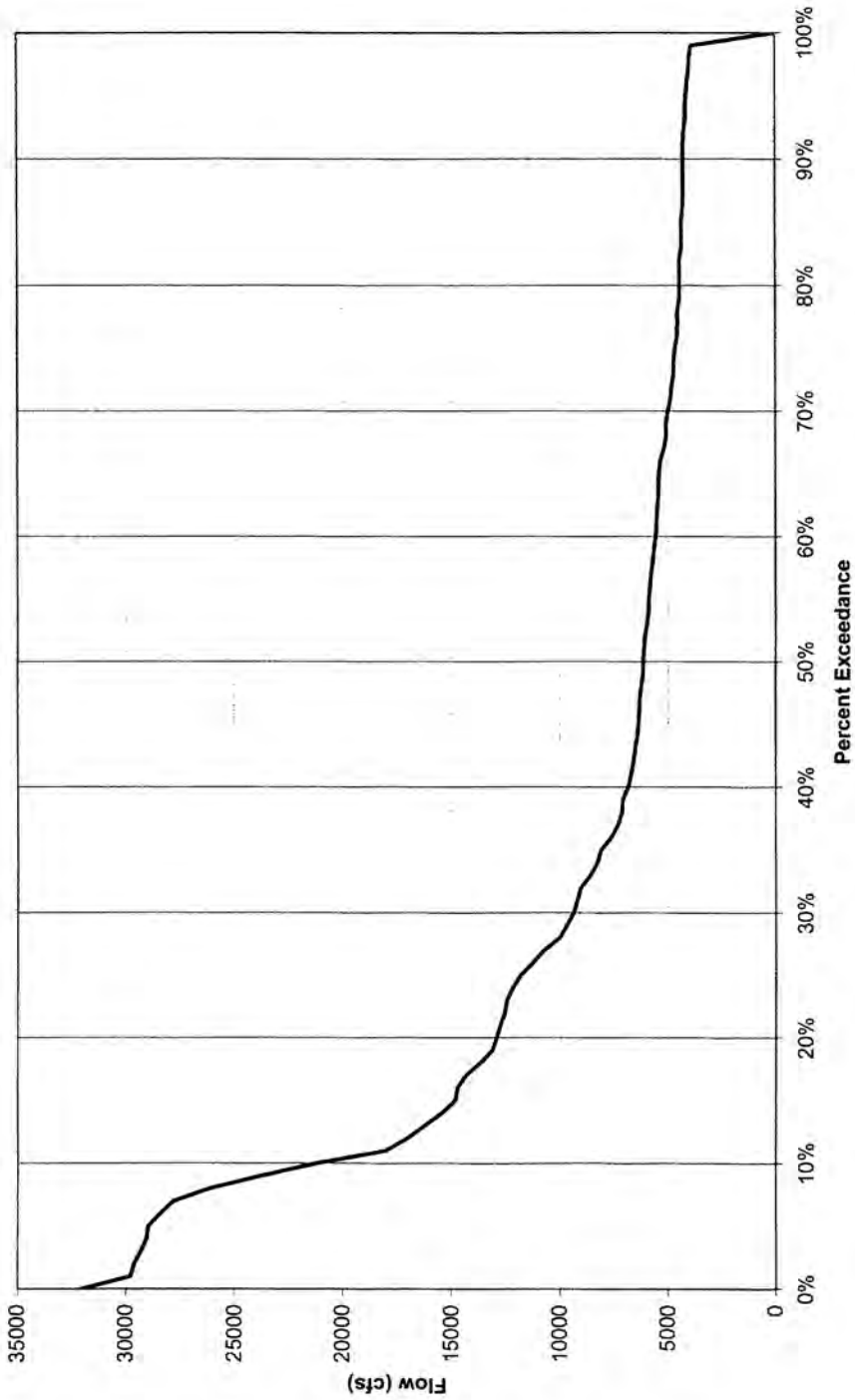
**Butler Creek October Flow Duration Curve**  
**1/1/1992 - 4/2/2002**



Butler Creek November Flow Duration Curve  
1/1/1992 - 4/2/2002



Butler Creek December Flow Duration Curve  
1/1/1992 - 4/2/2002



**Appendix F - Meeting Minutes**

## NEW SAVANNAH BLUFF LOCK & DAM FISHWAY CONSULTATION MEETING

### FINAL MINUTES

May 21, 2002, 1:30-4:30 p.m.  
Charleston, SC

#### 1. Introduction of Meeting Participants

Bill Bailey provided opening remarks and all parties provided introductions. (See attached list of Participants)

#### 2. Review Agenda and Purpose of Meeting

Bill Bailey provided an overview of the agenda and meeting purpose. (See Attached Agenda)

#### 3. Review Current Schedule For Fishway Design and Construction

Bill Lynch provided an overview of the current schedule of events, including concurrent efforts to repair the lock and dam structures (by others), and current project funding status. In the near term, the fishway design efforts will focus on narrowing down the field of potential design options to three preferred fishway options during the next month. At that point, a second agency consultation meeting will be scheduled (last week of June) to review and confirm the process/logic followed to arrive at the three preferred fishway design options. Resource agency participants will be expected to reach consensus on the final preferred fishway option at that meeting. The selected final preferred option will then be advanced to the 35% design level and cost estimate over the summer. The 35% design and cost estimate will then be used to secure funding for final design and construction phases of the project.

Resource agency personnel indicated concern with the schedule, that it may not be realistic to expect agencies to reach consensus on the final fishway preferred design at the June meeting. They indicated a commitment to try to meet the schedule, but suggested that a two week review period following the June meeting would be better.

#### 4. Review Fishway Design Efforts to Date and Resource Agency Involvement

Bill Bailey provided an overview of the subject design efforts completed to date, complete with resource agency involvement. He noted that this meeting was in response to resource agency comments on the 216 Report Addendum, indicating serious concerns with the fishway design proposed in the 216 Report, and requesting a new review of all potential fishway design alternatives.

Steve Gilbert said he wanted to compliment the Corps on their efforts to involve the resource agencies early in the process, and that it was in everyone's best interest to design the best possible fish passage for the site.

## 5. Confirmation of Resource Agency Design Criteria

### Prioritization of Target Species

- Steve Gilbert noted that there is an "Anadromous Fish Restoration Plan" for the Savannah River that has been accepted by FERC as a "Comprehensive Plan". He said it is a consensus document, not a full restoration plan. Steve Gilbert will send a copy of this plan to Steve Arnold
- Agencies indicated that some of the previously submitted design criteria have changed.
- It was emphasized that NSBL&D was the first of several dams in a series on the Savannah River and that the entire fish community of the river is influenced by this dam. All parties expressed a willingness and desire to maintain open lines of communication, and furthermore, to develop the best fish passage system possible.
- The design "target species" were discussed. Jeff Isely listed the species of interest he had collected in the project vicinity during recent years. After much discussion, it was agreed that if the following species/groups were targeted for passage, most species of concern would be benefited:

-Shortnose and Atlantic Sturgeon (information on lake or white sturgeon may be helpful). Boyd Kynard criteria for Atlantic sturgeon (5-8 ft long) is a minimum opening size of 3 ft wide by 2 ft deep.

-American Shad (surrogate for all Alosids including blueback herring and hickory shad).

-Robust Redhorse (surrogate for all sucker species).

-Striped Bass (spawning and thermal refuge movements).

-American eel (S. Gilbert noted this species will go through most fishways when migrating upstream, and would have little difficulty passing through a vertical slot ladder, nature-like bypass, or a rock ramp weir).

- The number of each species that need to be passed remains undefined.
- Jeff Isely commented that he has both shortnose sturgeon and robust redhorse tagged with radio transmitters. Although he will likely collect data useful in fishway design, the information will not be available in time for this phase of design.

- The Agencies did not want to prioritize, but expressed a desire to pass all species.

### **Hydraulic Design Criteria**

- Steve Gilbert provided two hand outs on hydraulic design parameters. One was for a “nature-like bypass channel” and the other was the design memo from Ben Rizzo dated 10/25/00 (submitted as part of the 216 Report Addendum comments from USFWS on 5/21/01).
- The Agencies expressed interest in a nature-like bypass channel, having a slope of 0.5 percent (3,000 feet or longer) and designed to pass all species. Since a natural channel would require the purchase of additional lands, it was recognized that this was a difficult hurdle to overcome. The agencies indicated that the “natural channel” concept was experimental in this region but noted the design had been successfully constructed and tested many times in Europe. The agencies remained interested in pursuing this design alternative
- A target hydraulic design basis for attraction flow, equal to around 5 percent of mean flow, was provided. This was estimated at approximately 600 cfs for spawning season (Feb. through June), or lower at other times of the year. Only a portion of the attraction flow needs to travel through the fishway, the remainder may be delivered directly to the fishway entrance as attraction flow.
- It was agreed that 20,000 cfs was the maximum river discharge for fishway design.
- The Agencies indicated that a Rock Ramp could be constructed on a slope steeper than 0.5 percent. It was noted that one advantage of this design was that a wide variety of hydraulic conditions are provided at different locations within the Rock Ramp structure, offering suitable passage conditions (both upstream and downstream) to a wide variety of species.
- The agencies indicated that they would like to see the fishway entrance and exit located as close to the dam structure as possible.
- The 2000 study performed by Rizzo was primarily directed at Shad and did not include Stripped Bass, robust redhorse, or Sturgeon. It was suggested that a submerged orifice large enough to pass a sturgeon (at least a 5-ft Atlantic sturgeon) would be needed in fishway baffles. However, submerged orifice designs caused problems for shad passage.
- Steve Gilbert suggested contacting Piotr Parasiewicz (Cornell Univ.), Boyd Kynard (Conte Lab, USGS), and Ben Rizzo as good information resources for fishway design criteria.



### **Operational Criteria**

- The spawning season was determined to be February to June, but there is also a fall run of Atlantic sturgeon. Agencies indicated they would prefer year-round fishway operation.
- The Agencies expressed a desire to provide both continuous upstream and downstream passage.
- The Agencies also indicated that as long as there are no turbines, the fish (with exception to adult sturgeon and maybe striped bass) would negotiate downstream passage through current gate operations. A rock ramp would also provide downstream passage for all species, providing the entrance was properly designed to attract downstream migrating fish.
- A question regarding adult sturgeon downstream passage, was directed at the gate sill elevation and the river bottom elevation immediately upstream of the dam. Would the elevation difference create a vertical lip that might function as a barrier to downstream sturgeon movement ?
- After much discussion, the agencies agreed that they just did not have good data regarding downstream movement. They agreed that with the possible exception of sturgeon and striped bass, the dam gates would serve as the primary downstream passage route. While downstream movement needed to be a design consideration, the fishway design effort should concentrate primarily on upstream movement.

### **O&M Considerations**

- Operation and maintenance of the system was discussed, including the transfer to the city of North Augusta. All parties agreed that a passive system with minimal annual O&M cost and labor requirements would most likely be the most attractive.
- In the future, lock operations will be infrequent and therefore should not be considered as the primary bypass system. The poor structural condition of the downstream lock wall was also noted as a reason to stay away from that location. Georgia DNR is also concerned about loss of shore based fishing access if the fishway were located in the lock or in gate #1.
- When looking at downstream flows, one should only consider flows since Thurman was placed into service in 1957.

## **6. Preliminary Discussion of Design Options**

- The last hour was dedicated to a review of current alternatives developed to date by Jon Truebe, including a rock ramp, lock passage via attraction flows and vertical slot fishway.

- Doug Cook suggested a fish lift should also be considered. While all agreed a lift is one of the most versatile fishways for a diverse mix of species, it also requires the most labor, maintenance and O&M commitment. It was agreed upon that without a Federal commitment to operate the fish lift, this alternative was not very attractive.
- Steve Gilbert expressed a desire for a passive system. He also indicated that he would like for the Corps to be responsible for monitoring, effectiveness testing and project enhancements prior to turning over operations and maintenance to the city of North Augusta. Therefore dollars must be included in the budget for:
  - A) Construction and short term modifications.
  - B) Defined term monitoring of effectiveness.
  - C) Defined term operations and maintenance.

With B & C determined to be approximately 2 years.

- It was also agreed that a fish lift, pumping, and locking were not practical primarily due to labor and O&M commitments.

#### **Next Meeting**

The next meeting was tentatively schedule for 10:00 am Thursday, June 27 (subsequently changed to June 26) to be held in Savannah. A preliminary report will be provided to the agencies during the week of June 17 – 23 (as earliest as possible). DE&S will provide these reports to Bill Bailey. Bill will then forward to the agencies. Steve Gilbert will provide a list of report recipients to Bill Bailey for direct mail (Steve will be out of the office).

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US FISH CHAS 65

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|                | C?                 | PHONE              |
|----------------|--------------------|--------------------|
| John Truette   | LET                | 609-359-1930       |
| Ron Grady      | Franktown ANP-DEIS | 704-382-2787       |
| Steve Arnold   | Franktown ANP-DEIS | (803) 775-4495     |
| Steve Givens   | USFWS              | (843) 727-1707 X12 |
| Ted Wain       | GA-DNR web         | (912) 727-2112     |
| Paul Lyons     | COE Sav. Dist      | (912) 652-5276     |
| William Bailey | COE Sav. Dist      | 912-652-5781       |
| Maurice James  | COE Mobile Dist    | 251-690-3109       |
| Tia Barrett    | GA - DNR           | 912 727 2112       |
| Ramon Martin   | GA-DNR             | 912 727-2112       |
| Jeff Bailey    | SC Compliance      | 864-656-1245       |
| Mark Collins   | SC DNR             | 843-762-5008       |
| Doug Renke     | SC DNR             | 843-825-3387       |
| Ed Bettrass    | GA DNR             | 706-595-1619       |

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**AGENDA**  
**NEW SAVANNAH BLUFF LOCK & DAM**  
**FISHWAY CONSULTATION MEETING**  
**May 21, 2002, 1:30-4:30 p.m.**

1. Introduction of Meeting Participants
  2. Review Agenda and Purpose of Meeting
  3. Review Current Schedule For Fishway Design and Construction
  4. Review Fishway Design Efforts to Date and Resource Agency Involvement
  5. Confirmation of Resource Agency Design Criteria
- (Note to Resource Agency Attendees – It is our intention to leave the meeting with the following criteria resolved so we can proceed with design work. Please be prepared to provide this information at the meeting.)**
- Prioritization of Target Species
    - Shortnose Sturgeon
    - American Shad
    - Robust Redhorse
    - Other Species
  - Hydraulic Criteria
    - Velocity Criteria
    - Depth Criteria
    - Attraction Flow Considerations
    - Operational Range (River Discharge)
    - Other Hydraulic Considerations
  - Operational Criteria
    - Upstream Passage Season of Operation (by species)
    - Downstream Passage Season of Operation (by species)
    - Year around operation to allow continuous fish movement
    - Operation and Maintenance Considerations
      - Low requirement for manpower vs. daily requirement
      - Certainty of operation (any designs limited by river discharge)
      - Certainty of operation (any designs limited by operation of lock)
    - Coordination with Lock Operation
6. Preliminary Discussion of Design Options
    - Location Preferences
    - Permitting Considerations
    - Initial Screening of fishway types (lift, lock, ladders, rock weir/natural channel/European designs, boat lock passage, gate passage, piggyback gate, etc....)
    - Maintenance requirements after a flood
      - Need for and ease of maintenance
      - Possibility of fishway alignment changing in response to high flows
    - Performance during a drought
  7. Open Discussion of Fishway Design Preferences.

## **NEW SAVANNAH BLUFF LOCK & DAM FISHWAY CONSULTATION MEETING**

**June 26, 2002  
10:00 a.m.-3:00 p.m.**

From 10:00 am to 3:00 pm on Wednesday, June 26, 2002, participants representing Framatome ANP DE&S (FDE&S), the Corps of Engineers (COE) and various agencies met at the COE Savannah District Office to discuss the second interim draft report of the fish passageway feasibility effort. The purpose of the meeting was to review actions to date, address outstanding configuration issues and attempt to narrow the field to one preferred alternative. Listed below is a summary of the items discussed. The list of attendees is attached to meeting minutes.

### **1. Opening and Introductions**

Bill Bailey passed out the meeting agenda and introductions were made.

### **2. Summary of the May 21<sup>st</sup> Meeting**

Design parameters were established for preparing and evaluating alternatives for the Fishway at New Savannah Bluff Lock and Dam. Targeted species for fish passage and options were identified and discussed. Sketches of preliminary designs were also introduced.

### **3. Preliminary Discussion Including Design Criteria**

- Steve Arnold (Framatome/Duke) led a discussion of the draft Evaluation Report that had been provided previously.
- The previous meeting minutes were recognized as well as comments received by all parties. The minutes will be revised to reflect any and all comments prior to the next report submittal.
- Steve briefly discussed the project background, the 216 report and overall study objectives.
- The previous study effort (rock gabion design) was discussed which drew various comments from the Agencies and resulted in the study effort currently being executed by FDE&S.
- The design criteria presented within the report was addressed in detail as well as comments received from the agencies. All comments received will be incorporated into the final report.
- All of the alternative fish passage schemes were discussed included FDE&S' narrowing the field to 3 alternatives. Mr. Brownell who was absent at the previous meeting has yet to submit comments, but does plan to do so prior to July 9. Early in this meeting, Mr. Brownell indicated that he would like to see the natural fish channel remain a candidate for consideration. Mr. Bill Lynch then stated that this alternative

would require additional land from an unwilling land owner. Furthermore, should this alternative be selected, the process could be delayed for an extended period of time. In any event, Steve Arnold indicated that the previously issued meeting minutes would be revised to reflect these comments to properly reflect the flow of information and paper trails.

- Steve Gilbert indicated that he was unable to narrow the field to one alternative and would like to carry 2 or 3 alternatives to a 35% design effort. Bill Lynch then responded that the COE has a narrow window of opportunity to carry the project forward and should the decision of a preferred alternative be delayed, there was chance the entire project could be delayed. In any event, it was mutual agreed upon that all was committed to installing the best possible option.
- Steve Arnold stated that headwater variation is not a problem at this location and that minimizing O & M costs will be a high priority when choosing one of the alternatives.
- Steve briefly summarized Section 4 in the report and there was some discussion regarding the protocol for gate operations particularly as it relates to the potential future downstream movement of fish. After some discussion, it was clarified that Gates 2, 3 and 4 (underflow gates) were raised and lowered as needed to control headwater elevation and meet the minimum bypass flow requirements of 3600 cfs. Gates 1 and 5 are normally operated as overflow gates and only pulled (completely out of the flow path) when flows reach approximately 20,000 cfs. There were questions regarding the COE's ability to effectively control headwater elevation/minimum flow by operating one gate as opposed to 3, thereby creating a more effective passage way for fish moving down stream. Maurice James stated that he would look into this possibility. The COE indicated they have no daily record of gate openings and are often operated several times a day.
- There was some question regarding the staff gage vs. NGVD correlation value. It was later determine that this figure was 100.58 as opposed to 101.0 as previously provided by the COE.
- Steve Arnold then went over the "target species". The following targeted species for fishway passage were discussed: American Shad, Shortnose Sturgeon, Robust Redhorse, Stripers and American Eel. It was stated that the Shortnose Sturgeons behavior limits alternatives to a 5% grade and Steve Arnold added that the swimming performances of various species affect the success of alternative designs for a fish passage structure.
- There was some discussion to document the work to date at the Cape Fear Fish Bypass System, which is scheduled for construction release in approximately 40 days. New plans are expected to be issued as a result of last weeks meetings.
- Steve discussed the need for a fish passageway system that could accommodate a wide variety of hydraulic design conditions (flow, speed, depth, etc.). He stated that there is not a downstream mortality problem here, as downstream passage is occurring through the gates, but that upstream passage is the primary concern. Steve

Gilbert stated that he is concerned about benthic-oriented species and their downstream passage.

- There was some discussion regarding recent actions were various parties have explored the possibility of installing a hydroelectric station near the facility. Bill Lynch stated that the COE's mandate is to proceed with the assumption that no hydroelectric power station will be located at the site. Should a hydro station be realized in the future, then proper consideration would need to be given to the passage of fish within the design of this new power station. In any event, future hydroelectric power station at this site is not a current design consideration.
- After some discussion, it was determined that the primary focus of this design effort would be to concentrate on the upstream movement of fish. However, the downstream movement of fish should also be a design consideration. Steve Arnold agreed to amend the previous meeting minutes to reflect this agency comment. Steve Gilbert then stated that he would like the downstream passage be addressed a bit more in the report.
- There was some discussion regarding the need for 1 ft. contours at the river/structure interface particularly as it relates to the ability of fish to negotiate through the gate openings both upstream and downstream. Maurice James agreed to look into this to determine what information was available.
- Doug Cooke asked if the thickness of the flow over the outside gates during drought situations is adequate for the passage of the surface-oriented shad. Maurice James responded that this thickness is one to two feet. It was stated that the basis for this design is a design flow of 3,600 to 20,000 cfs. There was continued discussion regarding the gate operations. Steve Arnold agreed to add a statement to the report that the design flow range for the bypass system would be between 3,600 cfs and 20,000 cfs. Furthermore, 600 cfs would be considered the maximum design attraction flow. Steve Gilbert indicated that the attraction flow values were acceptable.
- Steve Arnold stated that keeping the entrance and exit as close to the dam as possible is important.
- It was added that Striped bass congregate near gates three and four, while shad congregate near five.
- The phrase "bank overtopping" would be removed from page 17 of the report.
- Steve Gilbert indicated that maybe gate manipulations can be adjusted to best enhance performance of the fish bypass system.
- Several participants indicated that they would like to further study the location and configuration of the "Horseshoe" intakes.
- There was some discussion regarding the capacity of the fish bypass system. Steve Gilbert indicated that 50 fish per acre would be a good assumption.
- The bypass system entrance and exit was discussed. It was mutual that these structures should be as close to the dam as possible.



- Water Control – Steve Arnold is to remove the 16,000 cfs reference and leave “up to 20,000 cfs”.
- Mr. Brownell asked that design consideration be given to future monitoring. It was further stated that this should not be a considerable design effort. The agencies just did not want to miss an opportunity to consider future monitoring at this stage in project development.
- Stephanie Bolden asked if debris is a problem. The issue of debris was discussed. Apparently, debris tends to collect at the three center gates, but not at gates 1 and 5. Maurice James responded that during periods of heavy flow, it is not unusual to open gates and pass debris once per week.
- Steve Gilbert asked about access. The response was that access would be provided for the agencies. However, there would be no general public access in the area of the fish bypass system.
- The design depth of flow was discussed. There was discussion that 3 feet would be acceptable. Mr. Brownell indicated that 5 feet would be much better. This will most certainly be the subject of additional comments due no later than July 9.

#### 4. Evaluation of Alternatives

Mr. Jon Truebe reviewed in detail the alternative matrix presented in the report.

A matrix containing twelve fish passage alternatives was passed out. Nine were eliminated from further consideration because of the following reasons stated in parenthesis: Pool and Weir/Gabion (Difficulty of construction and Need for supplemental flow volumes), Full River Rock Ramp (No control of pool elevation), European/Natural Channel (additional real estate required), Denil Fish Ladder (not adequate to pass large sturgeons), Pool and Weir Fish Ladder (headwater sensitive, needs additional gates and multiple species problem), Mechanically Generated Currents in the Navigation Lock (High operational requirements), Gravity Flow Gate Manipulation in the Navigation Lock (High operational requirements), Fish Lift/Fish Lock (High operational requirements and High O&M costs) and Fish Pump (High operational requirements and High O&M costs). This elimination left three alternatives (in no particular order):

- Rock Ramp Gate No. 5
- Rock Ramp Horseshoe SC Side
- Vertical Slot Fish Ladder

The discussion then centered around these three alternatives. Steve Gilbert stated that he likes the in-river access of “Rock Ramp Gate No. 5” that “Rock Ramp Horseshoe SC Side” doesn’t provide. He felt this would aid upstream passage of fish. He also expressed concerns about the flows within the Horseshoe. It was stated that the Horseshoe allows the full 600 cfs to be carried downstream. Doug Cooke asked if the Horseshoe radius will cause a flow problem and Maurice James replied that the radius is sufficient. Several attendees expressed concerns about upstream passage for the Horseshoe and flaring at the entrances



was discussed. Steve Gilbert and Prescott Brownell stated that the "Vertical Slot" is their third choice with the other two being preferred. It was added that USFWS will contact Luther Aadlund for his opinion of the Horseshoe design. An attendee asked if the removal of Gate No. 5 could cause flooding. Maurice James replied that in 1934, when the Lock and Dam was built, there were no large dams upstream. He stated that this indicates no flooding should result from this gate removal. The Corps will check this to be sure. Prescott Brownell stated that the Horseshoe design may be better than the Gate No. 5 design for sturgeon passage. Maurice James stated that Gates 1 and 5 can be operated to control the thickness of the overflow. Steve Gilbert asked about the cost of the three options and Bill Lynch added that they are comparable. Bill Bailey stated that either the Corps or South Carolina could ask for an easement for road access if the Horseshoe design is selected. Steve Arnold asked which alternative the attendees preferred. Steve Gilbert replied that Gate No. 5 and the Horseshoe designs are equally appealing to him, with the Horseshoe design providing better downstream passage. Stephania Bolden wants Piotr Parasiewicz and Boyd Kynard to review the Gate No. 5 and Horseshoe alternatives and give recommendations. Maurice James favors the Horseshoe design as it stays away from the Lock and Dam structure. The structural engineers are somewhat concerned about additional weight being placed on the supports for the dam and excessive vibrations that some construction techniques could produce. Driving sheetpiles is of some concern to them. He added that for the Gate No. 5 option, a sheet pile cutoff wall would have to be placed and if the existing pilings under the dam are at an angle, this could be a problem. Stephania Bolden shared that she would like to have a minimum depth of water in the Horseshoe design of five feet throughout and Steve Gilbert added that a minimum three feet width is needed for sturgeon pectoral fin passage. (These criteria would also apply to the Gate No. 5 design.) It was stated that gates one and five are either completely open or completely closed and in the case of the Horseshoe design, these gates would be open and the upper pool would fluctuate little. Steve Gilbert stated that the gate operation routine will be specified by the Corps and required of the new owner. Joe Hoke added that the gate operation will be done remotely.

The natural channel was again a topic of discussion. It was agreed that a statement would be included in the report documenting that additional land would be required from an unwilling land owner and the other text would be removed from the report.

Steve Gilbert also indicated that he would like to recognize (in the report) that the lock can be used in the future also as a means of fish bypass.

Steve Gilbert requested the Corps evaluate potential modifications to the training wall located along the SC shore about 10 miles upstream of the dam. He is concerned that sturgeon could become trapped by the upper end of the training wall.

## 5. Conclusion

Six "Action Items" were identified:

1. Maurice James will look at the upstream bathymetry survey by Friday. This info will allow an assessment of the siltation upstream of the dam and any vertical steps that

would be encountered by benthic-oriented species attempting downstream passage. Savannah District will pass this info along to the agencies.

2. The Corps will develop hydraulic information on gate openings and velocities to allow determinations to be made on their adequacy for downstream passage. Savannah District will pass this info along to the agencies.
3. The Corps will distribute the Draft Report to Luther Aadlund for review (Done 26 June). The Corps had previously sent the report to Ben Rizzo and Piotr Parasiewicz. The USFWS will contact these individuals.
4. The Corps will distribute the Draft Report to Alan Blott (Done 27 June) and Boyd Kynard (Done 1 July) for review. The NMFS will contact them.
5. Comments on the preferred alternative are due to Savannah District (Bill Bailey) by 9 July from the two States and Federal agencies.
6. David Allen requested a copy of either the Draft Evaluation Report (if one is available) or the revised report. (Since we do not have any extra copies of the Draft, we will provide him with a copy of the revised report.)

**Appendix G****Correspondence**

**Appendix G.1     October 25, 2000 Rizzo Memo to Gilbert**

DEPARTMENT OF THE INTERIOR  
ENGINEERING FIELD OFFICE  
SUITE 612, ONE GATEWAY CENTER  
NEWTON CORNER, MA 02458-2802  
TEL. (617) 244 1368  
FAX (617) 527 6848

October 25, 2000

To: Steve Gilbert, (ES)  
Charleston SCFO

From: Ben Rizzo, FWS Engineering Consultant  
Newton Corner, MA



Subject: Suggestions for Improving Fish Passage at New Savannah Bluff Navigation Lock on Savannah River below Augusta, GA

Reference is made to your Sept 8/00 request for technical assistance in developing modifications to improve upstream fish passage at the existing navigation lock at the New Savannah Bluff Lock and Dam (NSBLD) Project on the Savannah River near Augusta, GA. This project was constructed by the Corps Savannah District.

Jeff Morris of the Corps Savannah District Planning Office forwarded our office some project plans in June/00 (at your request) to assist in our project review. We also received some project photos from Jeff in Oct/00 and additional project design and hydraulic data from Joe Hoke and John Hager of the Corps Savannah District. We understand the Corps is conducting a study regarding rehabilitation/decommissioning options for this project and has included as an option an agency recommended fish bypass channel at the SC side of the spillway to improve fish passage. A preliminary report on this study will be issued for agency review later this year.

The NSBLD is located at RM 187 on the Savannah River approx 12 miles downstream from the City of Augusta, Georgia. It is the lowermost barrier on the Savannah River which is the boundary between GA and SC. The average river discharge at this site is approx 9,550 cfs. The project consists of a five bay spillway (approx 350 ft long) spanning the river between concrete piers. A navigation lock (56' wide x 360 ft long lock chamber) is located on the Georgia shore. The spillway has two fixed crest steel gates at each end (each approx 60' wide) and three steel lift gates (each approx 60' wide) in the interior bays. The normal maximum head at the spillway and lock lift is approx 17 feet during low river flows (4,000 cfs). During high spring flows (above 25,000 cfs) the head drop at the drowned out spillway with raised interior gates can be as little as 6 inches. The headpond is normally kept near elev 114 - 115 by spillway gate manipulation, to facilitate a navigation channel upstream.

Existing Fish Passage

Currently upstream migrants pass this project by the periodic operation of the navigation lock during the spring migration season (March to May), or by passing over (or under) the spillway gates

during periods of higher than normal spring flows--- when there is very little drop at the spillway due to tailwater levels rising. Jeff Morris advised the city of Augusta is responsible for lock operations for fish passage and is supposed to follow a MOA signed in 1995 between the City of Augusta and Corps. It is our understanding (through Jeff Morris), the City has been lax in providing lock operations for fish passage in recent years and the lock was not in operation for most of this year due to need for lock repairs and safety issues.

#### River Flows During Spring Migration Period

We reviewed the tailwater and headwater data provided by the Corps and USGS and records of flow from 1952 to 1998 at the USGS Station at the project site ( Savannah River at Augusta, GA, DA = 7,508 sq miles) Our review indicates the following mean flows for the spring migration period:

| <u>Month</u> | <u>Mean Flow</u> | <u>Est HW Level</u> | <u>Est TW Level</u> | <u>Approx Head</u> |
|--------------|------------------|---------------------|---------------------|--------------------|
| Feb          | 12,420 cfs       | 114.5' NVGD         | 106.1' NVGD         | 8.4 ft.            |
| March        | 14,480           | 114.5'              | 108.0'              | 6.5 ft.            |
| April        | 13,320           | 114.5'              | 107.0'              | 7.5 ft.            |
| May          | 9,540            | 114.5'              | 103.5'              | 11.0 ft            |
| June         | 8,360            | 114.5'              | 102.3'              | 12.2 ft            |

Estimated Mean Annual Flow = 9,550 cfs

Estimated Minimum Daily Flow during Spring Migration Period = 4,000 cfs, Tailwater level = 98.0'

#### Suggestions for Improving Fish Passage at NSBLD

We suggest both operational and structural improvements to enhance fish passage via the navigation lock and spillway. As an alternate to passage through the navigation lock or the proposed experimental fish bypass channel at the left bank--- we recommend a new vertical slot fishway or fish lock constructed at the left spillway abutment (See attached conceptual plan). Following are some specific suggestions and comments:

#### Navigation Lock

o Operating Procedures ---We do not have details of the existing operational procedures for fish passage via the navigation lock, which may be included in the 1995 MOA between the Corps and the City of Augusta. We have outlined a suggested operation sequence (See attachment on last page-- Item #1), which includes separate lock operations for fish passage, maintaining a flow in the lock and operating partially opened lock gates during fish locking operations.

o New Side Entrance---( See Item #2 on conceptual plan)--- A new side entrance to the navigation lock wall is suggested as an appropriate measure to collect and pass migrants attracted to the spillway discharge. The navigation lock has a drain/fill culvert opening (approx 8' wide x 10' high) that runs along the length of each lock wall near the bottom. (See attached plan). This culvert and overhead pipe gallery complicate the placement of a side entrance. The side entrance channel should be opened to atmosphere (open channel flow) rather than a pressurized conduit or extension of the existing culvert system (proposed by Corps). We suggest a 6' wide x 13' high gated opening cut through the (gravity concrete) lock river wall near the downstream end of the spillway apron to facilitate collection of

migrants attracted to spillway flows. We have placed the floor of this side entrance at elev 96.0' to facilitate operation at lower river flows---this penetrates the upper portion of the drain/fill culvert. The new gate on the lock side of the new spillway entrance should be a downward opening segmented gate to provide a clear opening at low river flows and closure during lock fill operations. The pipe gallery forms the upper boundary of the side entrance. As river flows approach 16,000 cfs, the tailwater level will be at the top of the side entrance (approx El 109 ft) and we expect reduced passage efficiency at the side entrance due to submergence.

o Flow Deflector at Side Entrance---(See Item #3 on conceptual plan)--- To provide a suitable flow field at the side entrance to the navigation lock a flow deflector wall (concrete or steel) will probably be required to deflect the surface current from the spillway and enhance the jet from the spillway entrance. Field observations (and possibly a hydraulic model) will be required to determine and verify the location and design of the flow deflector..

o Fish Crowding Device We have no simple solution regarding a reliable and cost effective fish crowding device in the navigation lock. A trolley mounted screen type mechanical crowder (with hinged or hoistable crowder screen/rack) would be very expensive, would hinder navigation and require very restricted public access to the lock area during operation. We suggest a submerged high frequency sound system ("fish spooker" device in use @ St. Stephen fish lock) would be effective in moving adult alosids through the lock---this coupled with periodic seining would be our interim choices. We note there is a sill near the upper lock gate which extends approx 13' above the lock chamber floor ---this barrier may hinder the passage of shortnose sturgeon and other bottom migrants and requires further study.. We suggest an inclined ramp (grating type) be considered for future installation to enhance the upstream passage of these fish--- (See Item #7 on conceptual plan). A lock fishing sequence at night with partially opened lower lock gates and attraction flow may also be required to enhance sturgeon and Am. eel passage.

#### Spillway Gate Passage

Passage of upstream migrants occurs over the two fixed crest (crest elev = 112.5 ft) steel spillway gates at both ends of the spillway and/or under the hoistable interior spillway gates during periods of above normal river flow. We estimate there is very limited to no passage via the spillway gates during periods of normal or below normal river flows. The fixed crest spillway gates have ogee shaped crests which results in a surface backroll in the tailpool immediately below the spillway gates (plunging flow). This flow field is notorious and not conducive to effective upstream passage especially for surface oriented anadromous alosids. The back roll probably persists even during moderately high river flows (20 to 22k cfs) when tailpool is approx 1ft above spillway crest. To assist in create streaming flow conditions (no surface backroll) which is conducive to providing effective alosid passage, we suggest a surface notch be cut in both fixed crest steel spillway gates (at the shore ends), and a floor plate installed to create a broad crested weir. We suggest a notch 2' deep x 10' long x 6' wide---(See Item #4 on conceptual plan).

#### New Vertical Slot Type Fishway or Fish Lift at Spillway --- (See Item # 6 on conceptual plan)

As an alternate to (or to complement) the suggested navigation lock modifications and related special operations for fish passage---- and in place of the experimental fish bypass channel at the left bank proposed by Corps---we recommend a passive new vertical slot fishway or fish lift at the left end of the spillway be considered as the primary fish passage facility at this project. The attached conceptual plan shows a layout of a vertical slot fishway (with 10' W x 10' L x 5' min depth pools x 1.3' slot width). The fishway floor slope would be 1 on 16 providing a maximum drop of 9" per pool. This design is similar to the fishway proposed at the Columbia Hydroproject on the Broad River in Columbia SC. The fishway would be self regulating and would provide effective upstream passage of target migratory

species (and possibly shortnose sturgeon), up to river flows of 35,000 cfs. A fish counting station with viewing window and possible separate public viewing facility could also be incorporated in the exit channel of the fishway. A fish elevator or fish lock could also be utilized here as an alternate upstream passage device. We would be glad to provide your office additional details of either of these schemes at a later date. A floating trash boom is recommended in the headpond, upstream of the fishway or fish lift--- to guide floating debris and vegetation away from the fishway and towards the spillway. (See Item #5 on conceptual plan).

#### Fish Bypass Channel

We have reviewed the preliminary plans for the proposed experimental bypass channel submitted by the Corps Savannah District (in July/00) and have grave concerns regarding the effectiveness, anticipated high maintenance, hydraulics and aesthetics of the proposed facility (over 3 acres of rock filled gabions) in providing effective upstream passage. We note the lower segment of the bypass channel will be drowned out at above normal river flows during the spring migration period. The upper control gate is a bottom opening tainter gate which is either full open or closed and not suitable as a flow regulating device---a hinged bascule gate is suggested as more appropriate for water level control. Fish bypass channels should be considered at sites which have a good mix of erosion resisting natural substrates---- and not at sites which require extensive erosion control, sheet piling, cofferdams, leakage control measures and extensive site excavation like NSBLD. It is our understanding the estimated project cost is in the \$5.5 million range for this experimental facility. We trust other passage options will be pursued.

#### Preliminary Cost Estimates

Following are our preliminary cost estimates for the various fish passage enhancement measures based on year 2000 price levels. Please note these estimates are preliminary and subject to change based on additional project data and design investigations.

| <u>Item</u>                                                       | <u>Estimated Cost</u>        |
|-------------------------------------------------------------------|------------------------------|
| #1---Navigation Lock Operational Measures for Fish Passage        | (Not Determined)             |
| #2--- Gated Side Entrance to Navigation Lock                      | \$520k                       |
| #3--- Flow Deflector at Side Entrance                             | \$160k                       |
| #4---Notch in Fixed Crest Spillway Gates (2 @ \$20k)              | \$40k                        |
| #5--Floating Trash Boom in Headpond @ Fishway                     | \$50k                        |
| #6--Vertical Slot Fishway at Left Bank<br>(Alternate Fish Lift)   | \$4,400k<br>(\$3,700k)       |
| #7--Future Ramp (Grating) at Navigation Lock Floor<br>"Spokester" | \$290k<br>\$180k 5 11/2 0/1M |

Please excuse our delay in responding to your request and please call if you have any questions.

B.Rizzo/file = nsbld102.000



Item #1Suggested Locking Sequence at NSBLD Navigation Lock for Fish Passage

1. Fish collection in Lock Chamber --- Start with water level in navigation lock at tailpool level and upper miter gate closed. Close drain valve and partially open both lower lock gates (approx 12' - 15' wide) or only shore side lower lock gate (keep lower lock gate on river side in closed position). Partially open one or both fill valves to provide approx 1 fps current in lock chamber. Fish for agency designated time interval ( approx 1 hour during major migration period).

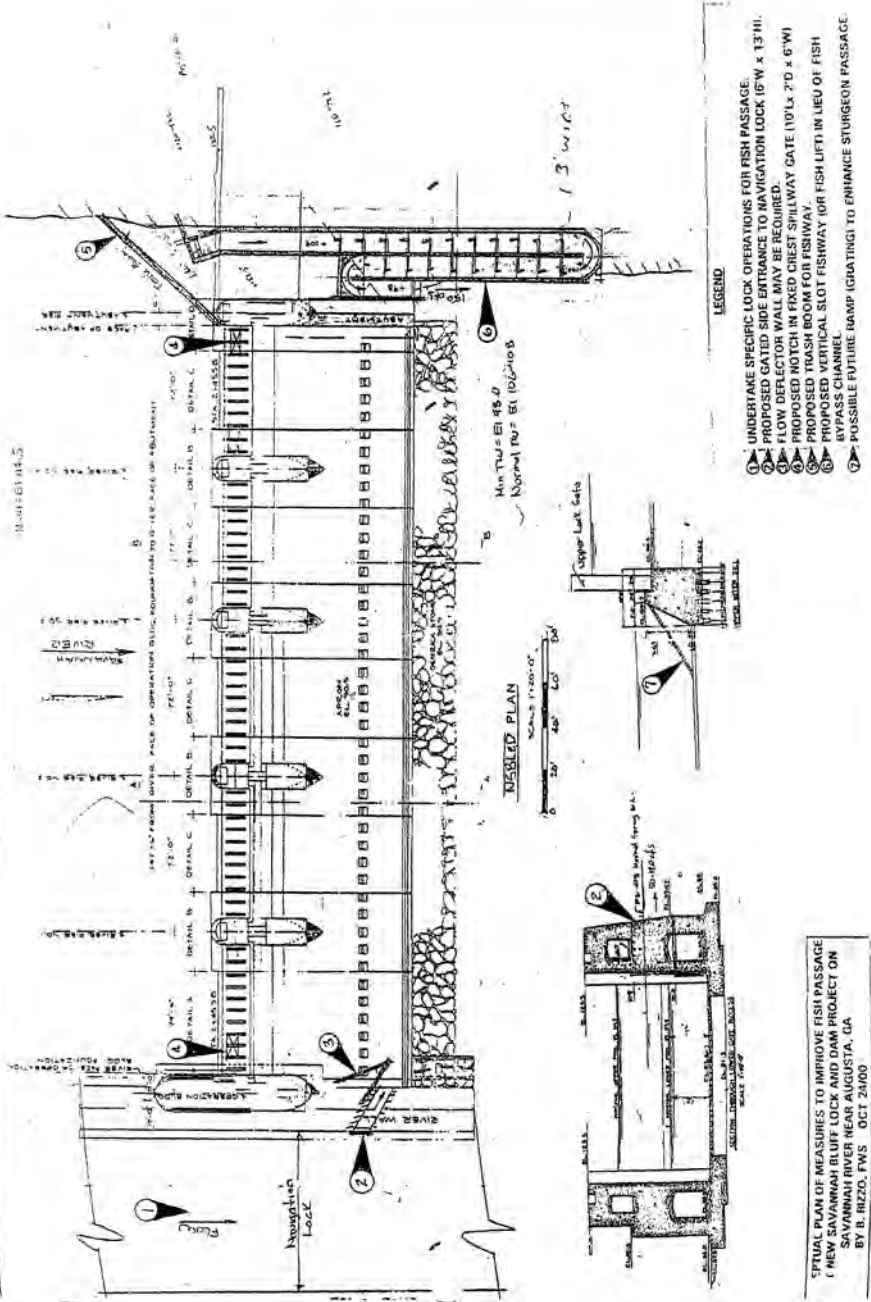
2. Fill Lock Chamber --- After designated fishing interval, close the opened lower miter gate and fill lock chamber slowly to headpond level. Can keep fill valve in partially opened position to allow lock chamber to fill to headpond level. (should take approx 10 - 15 minutes to fill).

3. Fish Passage from Lock Chamber to Headpond --- After lock chamber is filled to headpond level close fill valve and open or partially open upper miter gates (can partially open upper lock gates to 12 - 15' opening to increase current and/or allow scanning sonar counting). Open drain valve to allow approx 1 fps current into lock chamber from headpond via open upper miter gate to allow fish to exit lock. Can utilize high frequency sound "spooker" to enhance anadromous alosid movement out of lock chamber or other fish crowding device. Allow 20 - 30 minutes for fish to exit lock chamber.

4. Drain Lock to Commence Fishing Cycle ---- Close upper lock gate and open drain valve slowly in increments to drain lock to tailpool level (to minimize stressing fish remaining in lock or in reach below drain ports. Repeat locking sequence #1 to 4 above.

5. New Side Entrance Operation ---If a new gated side entrance to the navigation lock is constructed it would be opened or closed simultaneously with the lower lock gate (if tailwater levels are compatible) or can be operated alternately with the lower lock gate, as a separate fish entrance.

6. Modification of the above locking procedures may be required due to safety and operational problems.

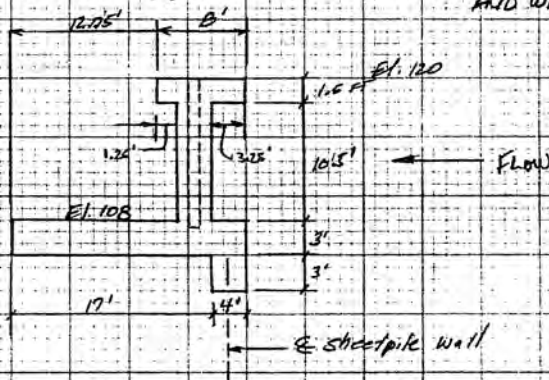


**A**

FRAMATOME ANP

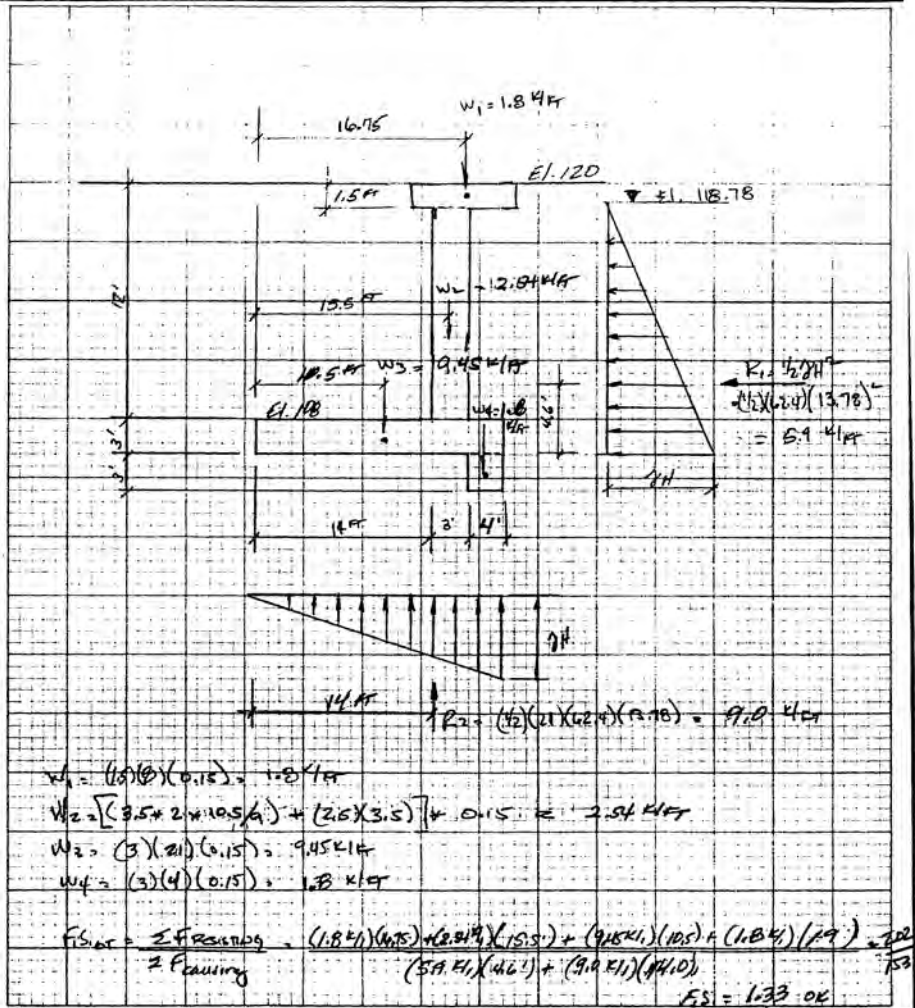
Framatome ANP DE&S  
CALCULATION GRAPH PAPERHEADWATER CONTROL STRUCTURE• ASSUMED DESIGN CONDITIONS

1. Upstream Pond Elevation =  $18.2 + 100.58 = 118.78$   
(Ref. Upper Pool Inundation Curve.)
2. Gates in closed position with NO WATER IN CANAL
3. EFFECTS OF SHEET PILE NEGLECTED
4. DESIGN FOR Full Hydrostatic Head & Associated uplift.

• Assume Following Configuration6. NEGLECT EMBEDDED  
AND WALLS

CHECK FS. OVERTURNING:  $\Sigma$  Forces Resisting  
 $\Sigma$  Forces Causing

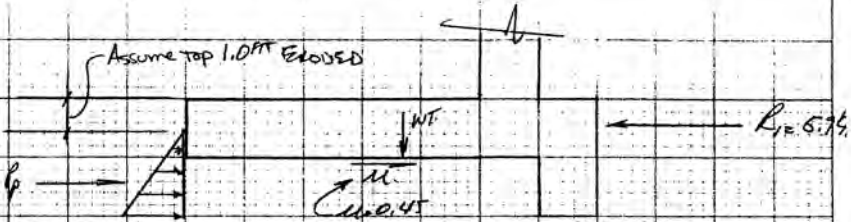
| Rev. | Orig. | Date | Chkd. | Date | Client/Project:                     |
|------|-------|------|-------|------|-------------------------------------|
|      |       |      |       |      | Subject:                            |
|      |       |      |       |      |                                     |
|      |       |      |       |      | Calc. No. _____ Sht. _____ of _____ |

**A****FRAMATOME ANP****Framatome ANP DE&S  
CALCULATION GRAPH PAPER**

| Rev. | Orig. | Date | Chkd. | Date | Client/Project:                     |
|------|-------|------|-------|------|-------------------------------------|
|      |       |      |       |      | Subject:                            |
|      |       |      |       |      |                                     |
|      |       |      |       |      | Calc. No. _____ Sht. _____ of _____ |

**A**

FRAMATOME ANP

Framatome ANP DE&S  
CALCULATION GRAPH PAPERCHECK F.S. W/L TO SLIDINGNeglect Resisting Forces  
@ ENDS OF STRUCTUREF.S. =  $\frac{\Sigma \text{FORCES RESISTING}}{\Sigma \text{FORCES CAUSING}}$ FORCES CAUSING:  $1.8K + 2.8K + 9.45K + 1.8K - 9.0K / (0.45) = 2.97 K/FT$ 

PASSIVE EP. CONTRIBUTION

$$= \frac{1}{2} \gamma H^2 \tan^2 (45^\circ - \frac{\phi}{2})$$

$$= \frac{1}{2} (120) (5.0)^2 \tan^2 (45^\circ - \frac{32^\circ}{2})$$

$$= 4.9 K/FT$$

Assume:  
 $\phi = 32^\circ, C = 0$   
 $\gamma = 120 K/FT^3$ 

$$F.S. SLIDING = \frac{2.97 K/FT + 4.9 K/FT}{6.9 K/FT} = \frac{7.87 K/FT}{5.9 K/FT} = 1.33$$

Note: Although the Factors of Safety for overturning & sliding are 1.33, respectively, the conservative nature of this calculation renders the structure stable.

| Rev. | Orig. | Date | Chkd. | Date | Client/Project:                     |
|------|-------|------|-------|------|-------------------------------------|
|      |       |      |       |      | Subject:                            |
|      |       |      |       |      |                                     |
|      |       |      |       |      | Calc. No. _____ Sht. _____ of _____ |

**A****Framatome ANP DE&S****FRAMATOME ANP**

DETERMINE F.S. OVERTURNING & SLIDING FOR NORMAL  
OPERATING CONDITIONS

I.C. HEADWATERS @ 115.5

OVERTURNING

$$H = 115.5 - 105 = 10.5 \text{ ft}$$

FORCES CAUSING

$$= (16)(62.4)(10.5)^2 = 3.4 \text{ K/ft} \leftarrow$$

$$+ (14)(21)(62.4)(10.5) = 6.9 \text{ K/ft} \uparrow$$

F.S. OF

$$= \frac{202.95}{(3.4 \text{ K/ft})(4.6') + (6.9 \text{ K/ft})(14.0')} = 1.81 \text{ OK}$$

SLIDING

F.S. SL

$$= \frac{9.87 \text{ K/ft}}{3.4 \text{ K/ft}} = 2.31 \text{ OK}$$

| Rev. | Orig. | Date | Chkd. | Date |
|------|-------|------|-------|------|
|      |       |      |       |      |
|      |       |      |       |      |
|      |       |      |       |      |

Client/Project: \_\_\_\_\_

Subject: \_\_\_\_\_

Calc. No. \_\_\_\_\_

Sht. \_\_\_\_\_ of \_\_\_\_\_

**Appendix I**

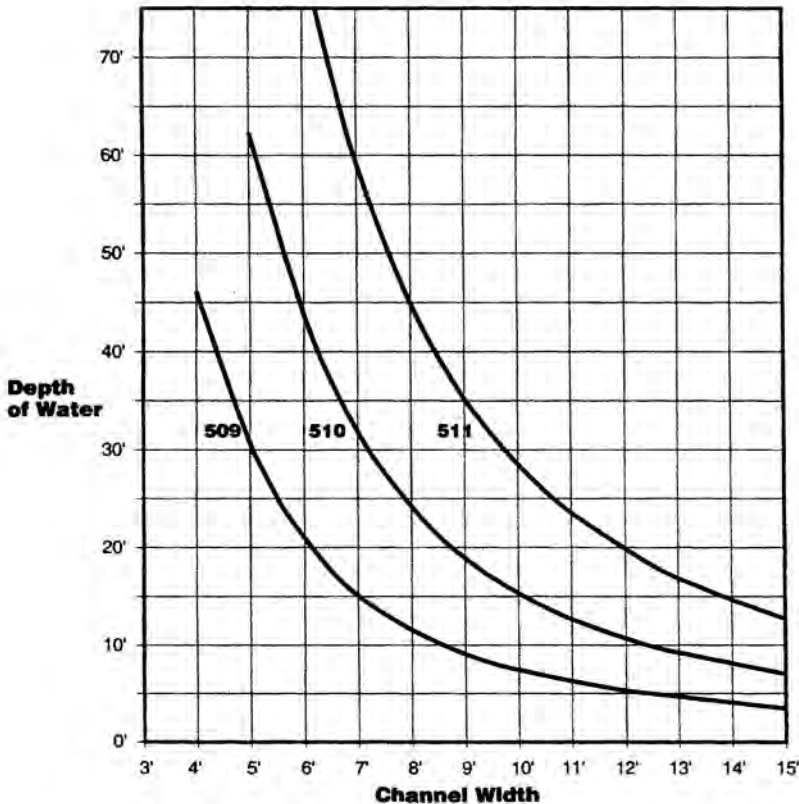
**Head Gate Information**

**Whipps, inc.****Series 500 Stop Logs****Aluminum Stop Logs****Introduction**

**Stop Logs** have been used for many years to contain water in ponds, tanks, or channels. They are used in applications where their installation or removal is required infrequently. Historically, stop logs have been made from squared timbers as their name suggests. The availability of wood in the sizes, quality and quantity to make traditional stop logs has become increasingly difficult. The lack of dimensional stability in wood also makes it very difficult to provide timber stop logs with predicatable leakage characteristics.

As the following chart illustrates, Whipps series 509, 510 and 511 Stop Logs are suitable for a large range of channel widths and water depths while providing a guaranteed maximum leakage rate of .05 gallons per minute per linear foot of wetted seal. This series of Aluminum Stop Log has been in continuous production since 1980 providing an affordable and effective water flow control alternative for many types of projects.

**Stop Log Application Chart**  
(@ 7600 P.S.I. Bending Stress)





# Whipps, inc.

## Series 500 Stop Logs

### Advantages

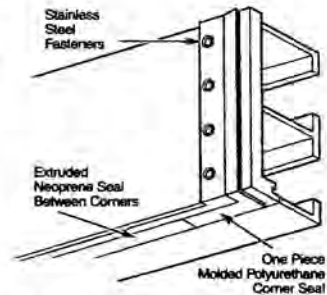
The following pages show the standard range of stop log heights, channel widths and total water depths. Many other configurations can be designed to customize these stop logs to accommodate other stop log heights, channel widths or total water depths.

All seals are designed to provide 1/8" compliance with the groove sealing surface and also designed to seal correctly when adjacent logs are laterally offset up to 1/2". All seals are stop log mounted for ease of inspection and repair and to eliminate the potential for damage from debris that is always possible when the side seals are mounted in the sides of the stop log grooves.

The Whipps Series of Proprietary Stop Log shapes are normally carried in stock which enables outstanding delivery of stop logs, including custom designs. Stop logs of this type have demonstrated excellent service life in both water and waste treatment plant applications.

### Design Features

- Stop Logs are aluminum (6061-T6), 5/16" minimum thickness and maximum 7600 psi stress.
- The specially shaped urethane seal attached to the bottom and ends of the stop logs provides an uninterrupted seal at the face of the stop log groove and the joint between the stop logs. The bottom stop log seals with the flush invert of the channel.
- The urethane seal is sufficiently compliant to deflect 1/8" under normal conditions of installation and wide enough to provide an adequate seal when adjacent stop logs are laterally offset up to 1/2".
- All contact surfaces for the stop log seals have a smooth mill finish.
- Welds on the down stream side of the stop logs are continuous.
- Adequate drainage is provided for the interior of the stop logs to prevent buoyancy or retention of water.



**View of Typical Bottom Corner**  
(Model 510, 12' High Shown)

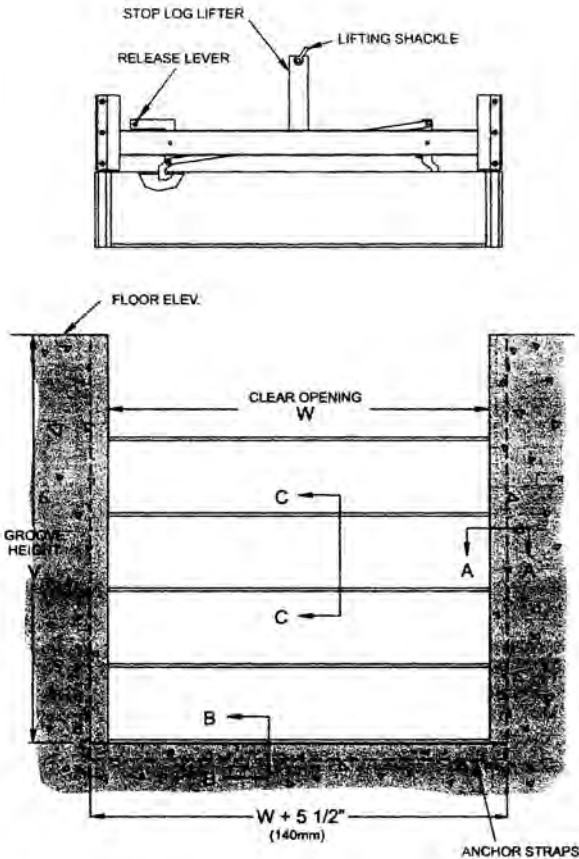
### Stop Log Grooves

- **Aluminum Stop Log Grooves** are one (1) piece aluminum (6061-T6) extrusions with integral concrete anchors for embedded applications. Face mounted and channel mounted applications as shown on pages 9, 11 and 13 are also available.
- **Stainless Steel Stop Log Grooves** are a formed and welded with integral concrete anchors for embedded applications. Face mounted and channel mounted applications as shown on pages 9, 11 and 13 are also available.
- **Cast Iron Stop Log Grooves** are cast with integral concrete anchors and machined on all stop log contact surfaces. This design is for embedded applications only.

# Whipps, inc.

### Series 500 Stop Logs

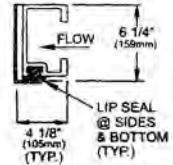
## Model 509



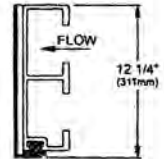
**NOTE: STOP LOG INSTALLATION ILLUSTRATED - 60" (W) X 66" (V)  
WITH (5) 12" HIGH MODEL 509 ALUMINUM LOGS AND LIFTER.**

**Model 509 Stop Logs** are made in the standard heights shown on the right. Please consult the factory if other heights are required. These stop logs are made of Alloy 6061-T6 Aluminum. However this size of stop log can also be manufactured from either Type 304 S.S. or Type 316 S.S. using the sealing system illustrated.

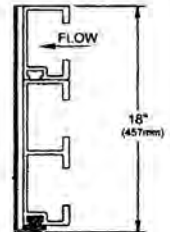
6" HIGH SECTION C-C  
(OPTIONAL)



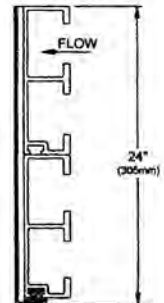
**12" HIGH SECTION C-C**  
(ILLUSTRATED)

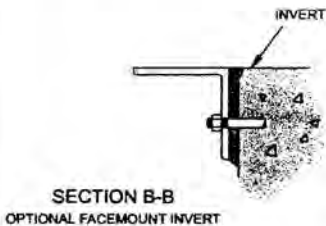
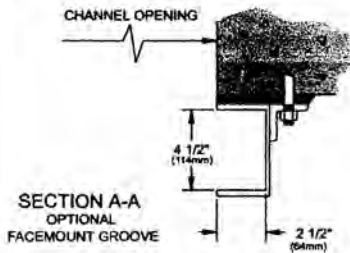
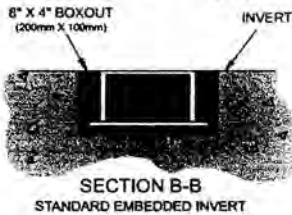
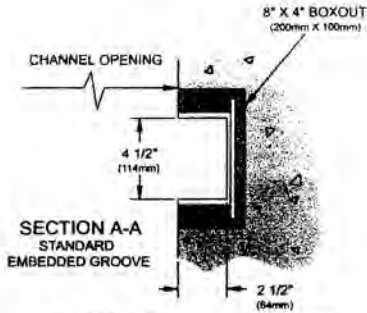


18" HIGH SECTION C-C  
(OPTIONAL)



24" HIGH SECTION C-C  
(OPTIONAL)

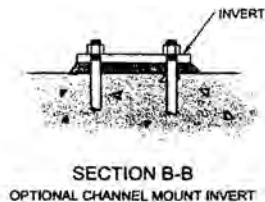
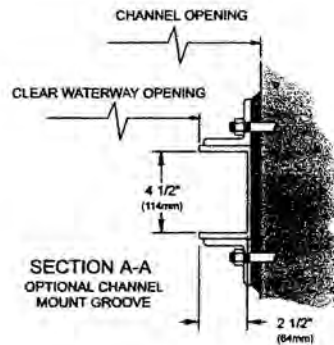


**Whipps, inc.****Series 500 Stop Logs****Model 509 Features****STOP LOG GROOVE FEATURES:****MATERIALS:**

- EXTRUDED ALUMINUM
- FORMED STAIN. STEEL
- CAST IRON

**CONFIGURATIONS:**

- EMBEDDED
- FACE-MOUNTED
- CHANNEL MOUNTED



# Whipps, inc.

**Yoke mounting** has two principal advantages: First, the gate and actuator are an integral unit which does not transmit operating thrust to the structure. Second, installation of this assembly does not require field alignment of the gate, stem and actuator.

**Pedestal mounted** actuators are preferred where the distance from the opening to the operating floor is relatively long, where a floor opening for the guides and yoke is not desired, or where the assembly is too large for efficient shipping and handling.

## Design Features

The following chart shows the gate features indicated by each model number. These models serve the commonly specified mounting and flow configurations. Custom designs are available for applications which can not be served by these standard models.

| GATE FEATURES           |                    | GATE MODEL NUMBERS |     |       |     |       |         |     |     |     |     |         |     |
|-------------------------|--------------------|--------------------|-----|-------|-----|-------|---------|-----|-----|-----|-----|---------|-----|
|                         |                    | 806                | 808 | 808-C | 814 | 815-D | 815-D-I | 816 | 820 | 825 | 835 | 835-D-I | 836 |
| FRAME STYLE             | Embedded           | X                  |     |       |     |       |         |     | X   |     |     |         |     |
|                         | Face Mount         |                    | X   |       | X   | X     | X       | X   |     | X   | X   | X       | X   |
|                         | Channel Mount      |                    |     | X     |     |       |         |     |     |     |     |         |     |
| SEALS                   | Side & Invert      | X                  | X   | X     |     | X     | X       |     | X   | X   |     |         |     |
|                         | Side, Invert & Top |                    |     |       | X   |       |         | X   |     |     | X   |         | X   |
| MIN. MATERIAL THICKNESS | 1/4"               | X                  | X   | X     | X   | X     | X       | X   |     |     |     |         |     |
|                         | 3/8"               |                    |     |       |     |       |         |     | X   | X   | X   | X       | X   |
| OPERATOR MOUNTING       | Yoke               | X                  | X   | X     | X   | X     | X       |     | X   | X   | X   | X       |     |
|                         | Pedestal           |                    |     |       |     |       |         | X   |     |     |     |         | X   |

## Optional Features

**Downward Opening:** All gate models can be specified for downward opening by adding a "D" to the model number. Such gates are used where there is insufficient vertical clearance to open a conventional gate or where the gate is to be used as an overflow weir. Downward opening gates may be furnished with or without a top seal (reference Model 815-D, page 14 and Model 815-D-I, page 16 and Model 835-D-I, page 26).

**Interconnected Stems:** All models may be specified with two interconnected operating stems by adding "I" to the model number. This type of stem arrangement is generally recommended for gates 72" or wider and having widths greater than twice their height (reference Model 815-D-I, page 16 and Model 835-D-I, page 26).

**Non-Rising Stems:** All models may be specified with non-rising stems by adding "N" to the model number. This operating stem arrangement is normally selected for operating installations with low headroom.

**Catalog Illustrations:** The twelve typical gate installations in this catalog illustrate a variety of gate models and sizes. Gate size and service conditions determine the actual gate configuration required for each new installation.

# Whipps, inc.

## Gate Selection Criteria

**Gate Size:** In water and waste water treatment plants, gates are most often sized to fit a pre-designed structure. In this regard, Series 800 gates offer great flexibility to accommodate any round, square or rectangular opening.

**Gate Mounting:** As shown in the model descriptions and their drawings, Series 800 gate frames may be embedded in the channel sides or mounted on the face of a wall or on the inside of an existing channel or on a wall thimble. These variations are designed to accommodate the mounting structure. Gate operation is not affected by mounting type.

**Gate Material:** Series 800 gates are constructed of aluminum (6061-T6 alloy) in either 1/4" minimum thickness (models 800-819) or 3/8" minimum thickness (Models 820-839)

**Actuator Selection:** The characteristics of the various types of actuators are discussed in the actuator section beginning on page 23. Operating loads are calculated as shown below. Manual operators should be selected to provide the calculated operating thrust with no more than 40 pounds effort. (For information regarding the selection of powered actuators, consult the factory.)

*Operating load is taken as the greater of the following two quantities:*

### ENGLISH UNITS

1.  $P = 50 h$   
where  
 $P$  = operating load (pounds)  
 $h$  = gate height (inches)
2.  $P = 12.48 A H$   
where  
 $P$  = operating load (pounds)  
 $A$  = area of opening (sq. feet)  
 $H$  = head on gate centerline (feet)

### METRIC UNITS

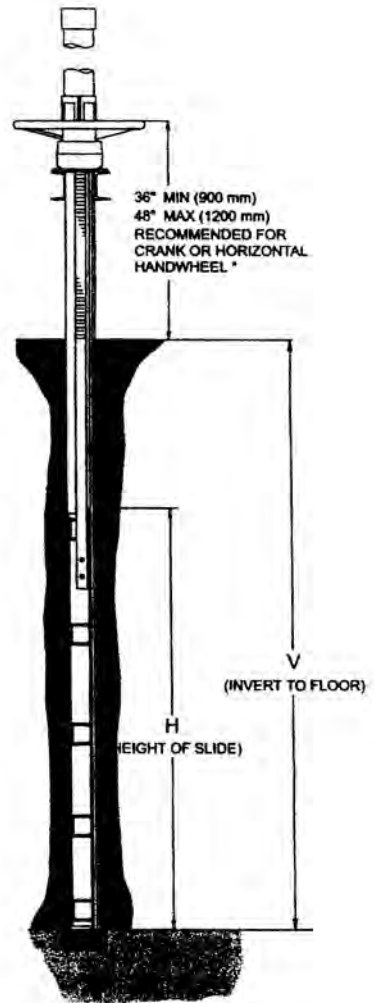
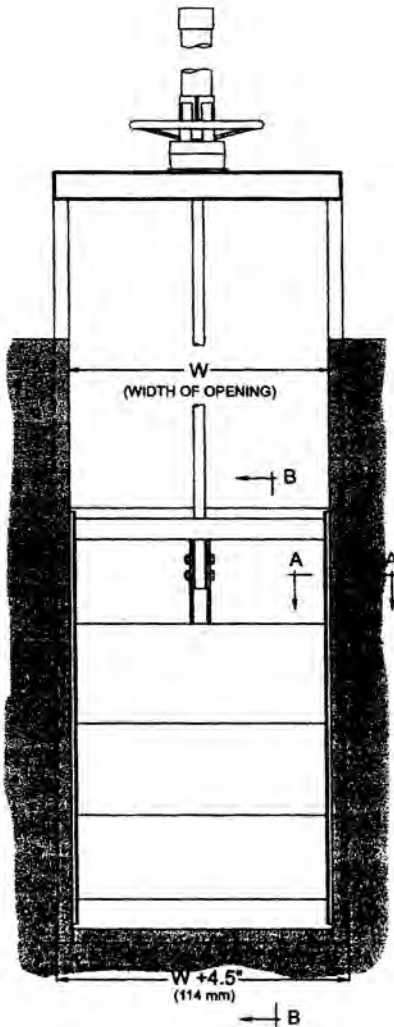
- $P = 8756 h$   
where  
 $P$  = operating load (newtons)  
 $h$  = gate height (meters)
- $P = 1961 A H$   
where  
 $P$  = operating load (newtons)  
 $A$  = area of opening (sq. meters)  
 $H$  = head on gate centerline (meters)

**NOTE:** Maximum operating loads are encountered during the first few inches of opening gate travel and the last few inches of gate travel during closing. Loads diminish quickly from these extremes.

**Actuator loads transmitted to the structure:** The stem thrust of pedestal mounted actuators is resisted by the structure supporting the gate and actuator. The structure must be designed to resist the maximum output of the actuator (e.g., electrical actuator at motor stall) which is necessarily greater than the operating load, sometimes much greater. Powered actuators use various devices to limit maximum output. However, the maximum output of manual actuators is only limited by the operator's effort.

# Whipps, inc.

## Model 806



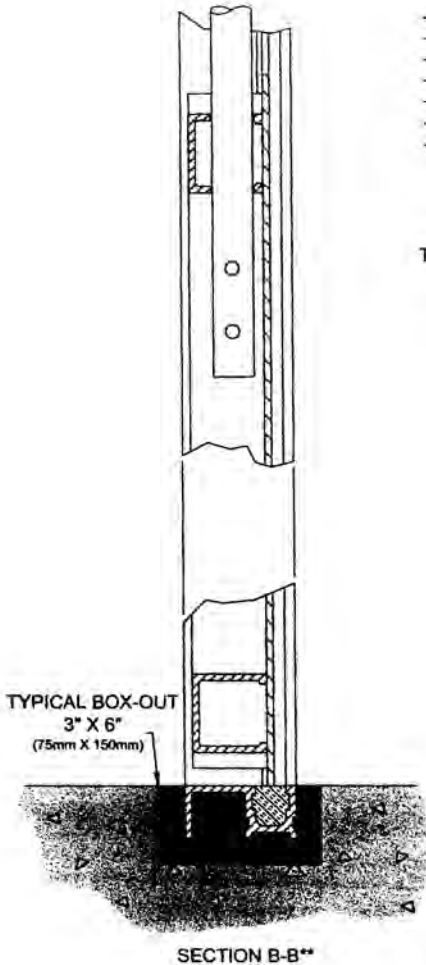
GATE ILLUSTRATED : 36" (W) x 60" (H) x 84" (V)

\* SEE ACTUATOR SECTION FOR OTHER ARRANGEMENTS

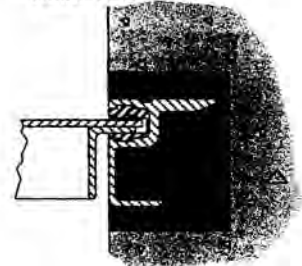
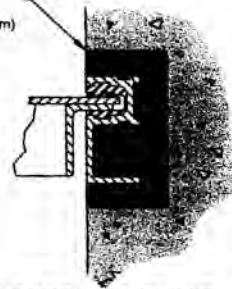
# Whipps, inc.

## Model 806 Features

- UHMW SEATS/SEALS
- LEAKAGE AS SPECIFIED IN AWWA C501
- EMBEDDED FRAME
- OPEN CHANNEL - NO TOP SEAL
- YOKE MOUNTED ACTUATOR
- 1/4" MINIMUM MATERIAL THICKNESS
- NEOPRENE INVERT SEAL (FLUSH BOTTOM CLOSURE)



TYPICAL BOX-OUT  
3" X 6"  
(75mm X 150mm)



\*\* SEE NOTE ON CATALOG ILLUSTRATIONS ON PAGE 4

# Whipps, inc.

## Gate Actuators

**Manual Actuators:** Manual actuators (handwheel or crank type) are used where operating loads are relatively low, where operation is infrequent or where electric power is not available.

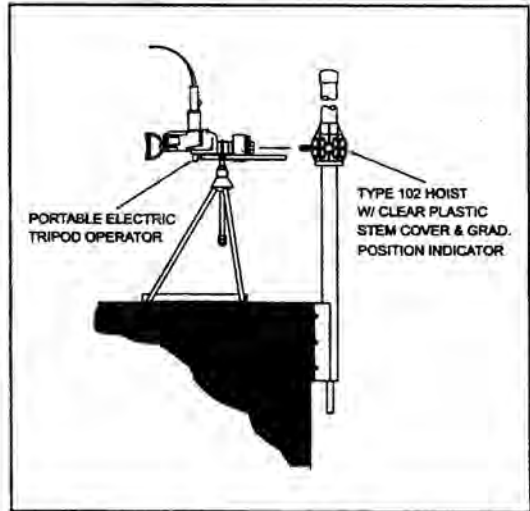
The term "handwheel type" is used to denote an actuator with a handwheel directly attached to the operating nut, concentric with the stem. This drives the nut at a one-to-one ratio.

The term "crank type" is used to denote an actuator with a horizontal input shaft which drives the operating nut through a right angle gear set. Drive ratios are available to operate virtually any gate, but it should be noted that at high ratios, e.g., greater than 8:1, the time and effort to manually operate a large gate is substantial. When crank type manual actuators are to be frequently used, or when they require many turns for full gate travel, portable operators should be considered (see comments in Portable Operator section below).

### Interconnected Operators:

For gates of great width relative to their height, as is common with overflow weirs, interconnected crank type actuators with a common input provide accurate positioning and smooth operation. These assemblies may be manually operated or electrically driven.

**Portable Operators:** Electric or gasoline powered portable operators of various configurations can be provided to drive crank type manual actuators. Consult the factory for details.



**Electric Actuators:** Electric actuators are used for higher loads, higher operating speed (12" - 24" per minute), or when gates are operated more frequently. Electric actuators can provide remote control of gate position and can be integrated into automatic control systems.

**Hydraulic Actuators:** Hydraulic actuation can provide smooth and fast operation and is particularly well suited to automatic control systems which may generate frequent modulation of the gate. With suitable accumulators, hydraulic actuators can provide automatic gate positioning upon electric power failure.



**Appendix J****Internal Technical Review**

## QUALITY CONTROL PLAN

### Thirty-Five Percent (35%) Design Effort Fish Passage – Phase II NEW SAVANNAH BLUFF LOCK AND DAM

#### PROJECT SYNOPSIS

Framatome ANP DE&S (FDE&S) will complete the feasibility level design (35% percent) for the COE selected horseshoe type fish passage system at the New Savannah Bluff Lock and Dam (NSBL&D). This design effort will be executed in accordance with the five (5) primary tasks listed below. Additional details are provided in the approved work scope for Contract Number DACW01-00-D-0019, Task Order Number 0006.

- |        |                                                                                          |
|--------|------------------------------------------------------------------------------------------|
| Task 1 | Preferred Project Layout & Report Outline                                                |
| Task 2 | Submit General Arrangement Drawings and Report Outline                                   |
| Task 3 | Generate Engineering Appendix for Feasibility Design Report and Detailed Layout Drawings |
| Task 4 | Agency Consultation/COE Internal Review Meetings                                         |
| Task 5 | Document Revisions and Final Report Submittal                                            |

#### PROJECT TEAMS MEMBERS

|              |                                 |                      |
|--------------|---------------------------------|----------------------|
| Jim Medford  | Project Manager                 | FDE&S                |
| Ron Grady    | Civil Engineer & Technical Lead | FDE&S                |
| Steve Arnold | Fisheries Biologist             | FDE&S                |
| Jon Truebe   | Fisheries Engineer              | Lakeside Engineering |

#### INDEPENDENT TECHNICAL REVIEW TEAM

|             |                     |       |
|-------------|---------------------|-------|
| Chris Ey    | Hydraulic Engineer  | FDE&S |
| Ed Luttrell | Engineering Manager | FDE&S |
| Mike Murphy | Project Manager     | FDE&S |

#### SCHEDULE

##### Task 1 – Preferred Project Layout

Review Existing Data (Week 1)  
 Request Additional Data/Information (Week 1)  
 Submit Quality Control Plan (Week 1)  
 Perform Hydraulic Analysis (Weeks 2-4)  
 Perform Earthwork and Geotechnical Studies (Weeks 2-4)  
 Determine Recommended Canal Alignment Configuration (Weeks 2-4)  
 Design the Headwater and Tailwater Structure Configurations (Weeks 2-4)  
 Determine Project Access Requirements (Weeks 2-4)  
 Identify Potential Sources of Construction Materials (Weeks 2-4)

Determine Excavated Material Disposal Requirements (Weeks 2-4)

Develop Annotated Draft Engineering Appendix Outline & Prel. Drawings (Weeks 5)

**Task 2 - Submit General Arrangement Dwgs & Draft Report Outline (Week 6)**

**Task 3 - Draft Engineering Appendix for the Feasibility Report & Detailed Layout Drawings (Weeks 7-9)**

Project Feasibility Design

Project Schedules

Quantity Estimates and Cost Estimates

**Task 4 - Agency Consultation & ITR (Weeks 10-11)**

**Task 5 - Document Revisions and Final Report Submittal (Weeks 12-13)**

**Listed below is documentation of the ITR provided by Mr. Steve Arnold (Fisheries Biologist), substituted for Mike Murphy (as approved by Mr. Maurice James USACE).**

Steve - My response to your comments is listed below. Please note that Jon will address the issue of gate flow velocities. Thanks again and let me know if you have further questions.

Ron Grady  
Sr. Project Engineer  
Hydropower & Natural Resources

-----Original Message-----

**From:** ARNOLD Stephen  
**Sent:** Tuesday, December 03, 2002 12:03 PM  
**To:** GRADY David R.  
**Cc:** Truebe, Jon (E-mail)  
**Subject:** New Savannah Bluff Lock & Dam Technical Review

Ron

As you requested in your letter of 12/5/02, I have completed your requested internal technical review on the Draft Fish Passage Report for the New Savannah Bluff Lock & Dam. I have reviewed the report both from a technical perspective and also offer editorial comments. My comments are listed below:

- p.2, Task 3, last sentence, anticipate s/r anticipated **[GRADY David R]** (Completed)
- p.9, C.3. 1st para., last sentence, insert Phase I after the word draft **[GRADY David R]** (Completed)
- p.12, 2nd. para., 7th line, says "design maximum head of 17 feet", but p.20 says 17.5 feet **[GRADY David R]**

The report will reference the following operating pond elevations and resulting design differential heads:

**Headwater:**

High Headwater Operating Level - 115.5  
Normal Headwater Operating Level - 114.5  
Low Headwater Operating Level - 113.5

**Tailwater:**

Normal Tailwater Operating Level - 101.5  
Extreme Low Tailwater Operating Level - 98.0

**Resulting Design Heads:**

Normal Design Head - 14.0 feet  
Extreme Maximum Design Head - 17.5

- p.13, Section C, 2nd para., says " maximum head is estimated at about 17 feet", but p.20 says 17.5 feet **[GRADY David R]** (See Note above)
- p.16, 1st line, 1996 s/r 1998 **[GRADY David R]** (Completed)
- p.20, Section B.1.3.3, 2nd sentence, says "The maximum head is 115.5 feet minus 98 feet, or 17.5 feet.", but pp.12 & 13 say 17 feet **[GRADY David R]** (See Note above)
- p.20, references to Figures 4, 5, and 6 are out of sequence. **[GRADY David R]** Noted
- p.21, 2nd para., next to last sentence, delete extra period at end **[GRADY David R]** Completed

- p. 21, bottom of page. Table of head gate velocities, shows velocity through the head gates of approximately 2.94 to 3.75 ft/sec. Given this is the only place in the fishway where velocity is relatively uniform across the entire fishway channel, are these velocities suitable for passage of all target species ? It seems to be a little high. **[GRADY David R]** (Jon Truebe to address under separate cover)
- Appendix D is empty. Are Material Quantity estimates presented elsewhere in the report? **[GRADY David R]** (Correct and Noted)
- Appendix F. Delete the "DRAFT" in the upper right hand corner. These are Final Meeting Minutes. **[GRADY David R]** (Completed)

If you have any questions regarding these comments, please give me a call.

Steve Arnold

**Stephen H. Arnold**  
**Senior Aquatic Scientist**  
**Framatome ANP DE&S**  
**500 Washington Ave.**  
**Portland, Maine 04103**  
**Phone: (207) 775-4495**  
**email: (NEW)**  
[stephen.arnold@framatome-anp.com](mailto:stephen.arnold@framatome-anp.com)

**Listed below is documentation of the ITR provided by Mr. Ed Luttrell (Engineering Manager, Framatome ANP-DE&S).**

Ed - Your comments have been incorporated into the subject report

Thanks  
 Ron Grady  
 Sr. Project Engineer  
 704-805-2787

-----Original Message-----

**From:** LUTTRELL Ed C  
**Sent:** Monday, December 09, 2002 4:32 PM  
**To:** GRADY David R  
**Subject:** FW: Report Review

I will be in a meeting until mid-day Monday, so I am sending these comments from home .. The report looks good, comments are mostly editorial.

ED

Pg 2, Task 3: "It is also anticipatedd that the ..."

Pg 8, C.1, 8th line: "...during a meeting..."

Pg 9, C.3, 4th Para: how about complicated vs. compounded

Pg 10, 3rd Para: no comma after horseshoe design

Pg 12, B.1, 1st Para: The borings were advanced to depths of (vs. have)

Pg 12 : Through out report you switch between x.0 and just x for elevations, be consistent

Pg 13, B.2, 3rd bullet: confirm listing status, federal ? state ? rare, threatened, endangered ?

Pg 13, C., 2nd Para: I would not say "slightly underestimate" without data, what about striking slightly

Pg 14 1st Para: Are all upstream flows from generation, no accretion flow or spill ?

Pg 15, A.1: you cap. Resource Agencies one place and not another

Pg 16, last line: "...and is not a design..."

Pg 20, B1.3.2: footnote 1 is not needed since table calls out avg. velocity

Pg 21, 2nd Para: should it be expected to reduce (vs. remove)

Pg 23, B.1.3.7, 2nd bullet: congregated (noting)

Pg 24, B.1.4, 1st Para: drawings are numbered SAVANNAH1,2,3, etc.

Pg 24, B.1.4, 2nd Para: delete one "are placed" and pattern, not patter

Pg 24, B.1.4, 3rd Para: "protected from erosion by a 2 ft"

Pg 24, B.2.1, 3rd bullet: suggest "vehicle" instead of "rolling stock"

Pg 25, B.2.3: is, not id

Pg 26, 1st Para, 5th line: lowered, not lower

Pg 26, 2nd Para: suggest "minimum ( reinforcing needed for crack control)."

Pg 35, B.3.1, 2nd bullet: suggest "with equipment" versus "via rolling stock"

Pg 37, 2nd Para: suggest "existing" trees versus "natural trees (is there any other kind ?)

Is the hydrostatic pressure right on Figure 9 ???

On drawing 1, should you label the heavy dash-dot line .... is it property boundary ??

On drawing 2, note in lower left should be WATER WAS TOO SHALLOW, not TO

**Listed below is documentation of the ITR provided by Mr. Chris Ey (Civil /Hydraulic Engineer, Framatome ANP-DE&S)**

Ron,

Per your request, I have reviewed the Savannah Bluff Draft Engineering Report dated November 2002. Based on my review the report appears to be prepared in accordance with standard engineering industry practice. I do not have any specific technical comments. I noted several editorial -type recommended corrections on the draft copy I reviewed. Please review and incorporate as appropriate.

Chris

-----Original Message-----

**From:** GRADY David R  
**Sent:** Monday, December 02, 2002 5:19 PM  
**To:** ARNOLD Stephen; EY PE Chris; LUTTRELL Ed C  
**Subject:** Savannah Bluff - Internal Technical Review

Steve - Here is the letter we talked about. Please provide me with your written comments.

Ed and Chris, we can discuss on Thursday.

Ron Grady  
 Framatome ANP DE&S  
 400 South Tryon Street  
 Charlotte NC 28285  
 Phone: 704-805-2787  
 email: ron.grady@framatome-anp.com

<< File: Internal Review - December 5.doc >>



**Listed below is documentation of the internal client review provided by Mr. Maurice James (USACE Engineer)**

Maurice - Your comments have been incorporated into the subject report. Thanks and let me know if you have any questions.

Ron Grady  
Sr. Project Engineer  
704-805-2787

-----Original Message-----

**From:** Maurice.James@sam.usace.army.mil [mailto:Maurice.James@sam.usace.army.mil]  
**Sent:** Monday, December 09, 2002 10:04 AM  
**To:** Ron.Grady@framatome-anp.com  
**Subject:** RE: NSBL&D Fishway Draft Engineering Report Comments

Ron,

Attached are my comments. I think you have them from the meeting but this will give you a reference and make it "official".

MJ

-----Original Message-----

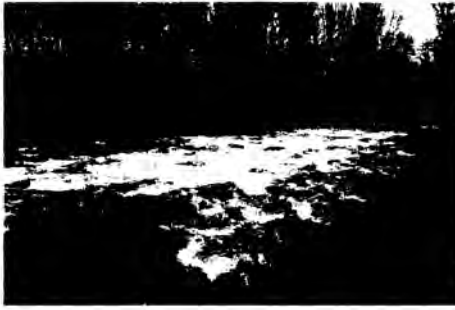
**From:** GRADY David R [mailto:Ron.Grady@framatome-anp.com]  
**Sent:** Thursday, December 05, 2002 1:19 PM  
**To:** Maurice James (E-mail)  
**Cc:** William G. Lynch (E-mail)  
**Subject:** NSBL&D Fishway Draft Engineering Report Comments

Maurice - As discussed, please forward to me any pertinent internal COE comments to the draft report.

Thanks

Ron Grady  
Framatome ANP DE&S  
400 South Tryon Street  
Charlotte NC 28285  
Phone: 704-805-2787  
email: ron.grady@framatome-anp.com

**Appendix K      Other Miscellaneous Information**



Location: Bad Bodendorf, Germany  
River: Ahr  
Type: rock ramp fishway  
Slope: 1:25  
Headloss: 1.60m  
Width: 25m  
Flow: 1.20m<sup>3</sup>/s min. to 9.60m<sup>3</sup>/s  
Designer: Gerbler  
Picture Source: Uli Dumont





Location: St. Laurent des Eaux, France

River: Loire

Type: step-pool rock ramp fishway

Slope: 1:50

Headloss: 16in max. per step, 6ft dam height

Width: 52.8ft

Length: 264ft

Flow: 63-835cfs (design), 12,670cfs (mean annual)

Designer: Travade

Picture Source: Travade



Location: near Churchill, Canada

River: Churchill

Type: rock ramp fishway

Slope: 1:30

Headloss: 1.8m, 2m dam height

Width: 2.3km long weir, 300m wide ramp

Flow: 75m<sup>3</sup>/s (min.), 150cfs (10%ile Sept.)

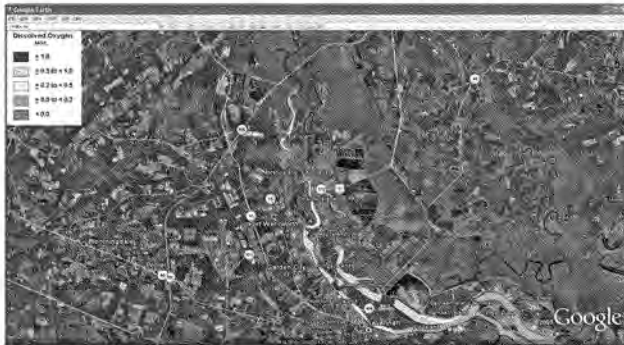
950m<sup>3</sup>/s (90%ile open water), 1500m<sup>3</sup>/s (100yr)

Designer: Manitoba Hydro

Picture Source: Chris Katopodis

---

# Oxygen Injection Design Report Savannah Harbor Expansion Project Savannah, Georgia

**PREPARED BY:**

Tetra Tech, Inc.  
2110 Powers Ferry Rd. SE, Suite 202  
Atlanta, Georgia 30339  
Phone: (770) 850-0949

**PREPARED FOR:**

USACE Savannah District  
100 West Oglethorpe Ave  
Savannah, Georgia 31401  
Contract No: W912-HN-05-D-0014  
Work Order 0025

**FINAL**  
**October 15, 2010**

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## 1.0 INTRODUCTION

The United States Army Corps of Engineers (USACE), Savannah District is working with the Georgia Ports Authority (GPA) to evaluate the deepening of the navigation channel in Savannah Harbor. This effort is called the Savannah Harbor Expansion Project (SHEP). The project is intended to identify the impacts and mitigation strategies of deepening the harbor from its presently authorized 42-foot depth Mean Lower Low Water (MLLW), up to a depth of 48-foot MLLW.

Hydrodynamic and water quality models were developed and determined to be acceptable in March 2006 by the United States Environmental Protection Agency (USEPA), United States Fish and Wildlife Services (USFWS), Georgia Environmental Protection Division (GAEPD), and South Carolina Department of Health and Environmental Control (SCDHEC) to identify dissolved oxygen (D.O.) levels throughout Savannah Harbor. Studies have identified a dissolved oxygen injection system as being the most cost effective method to improve dissolved oxygen levels in the harbor (MACTEC 2005).

The SHEP is examining ways to mitigate for potential adverse effects on dissolved oxygen levels from proposed harbor deepening alternatives and will use oxygen injection systems for that mitigation. To meet those mitigation requirements, designs for an oxygen injection system were needed. This work effort uses the models to size and locate the system components and ensure the dissolved oxygen effectively mixes throughout the portions of the harbor that have the critical dissolved oxygen impacts.

The dissolved oxygen improvement designs are based on use of an off-stream (land-side) system to improve the dissolved oxygen of waters obtained from the harbor, and then reintroduce those oxygenated waters back into the harbor. The designs are based on the Speece cones to increase the oxygen levels.

The basic tasks included in this *Oxygen Injection Design Report* are as follows:

- Review siting of D.O. Injection Systems
- Optimize the D.O. discharge for mitigation purposes
- Accomplish near-field plume modeling for discharge sites
- Accomplish all necessary additional far-field model runs

## 2.0 TECHNICAL APPROACH

In developing the models for the Savannah River Estuary (Savannah Harbor), the Environmental Fluid Dynamics Code (EFDC) was selected for the hydrodynamic model. The Water Quality Analysis Simulation Program Version 7.0 (WASP7) was used for the water quality model development.

The EFDC model is part of the USEPA TMDL Modeling Toolbox due to its application in many TMDL-type projects. As such, the code has been peer reviewed and tested and has been freely distributed for public use. EFDC was developed by Dr. John Hamrick and is currently supported by Tetra Tech for USEPA Office of Research and Development (ORD), USEPA Region 4, and USEPA Headquarters. EFDC has proven to capture the complex hydrodynamics in Savannah Harbor and similar systems. The EFDC hydrodynamic and sediment transport model linked with the WASP water quality model provided the most appropriate combination of features necessary for this study. EFDC is a multifunctional, surface-water modeling system, which includes hydrodynamic, sediment-contaminant, and eutrophication components. The EFDC model is capable of 1, 2, and 3-D spatial resolution. The model employs a curvilinear-orthogonal horizontal grid and a sigma, or terrain following, vertical grid. The EFDC model's hydrodynamic component employs a semi-implicit, conservative finite volume-finite difference solution scheme for the hydrostatic primitive equations with either two or three-level time stepping (Hamrick 1992).

The EFDC hydrodynamic model can run independently of a water quality model. For this Savannah Harbor application the EFDC model simulates the hydrodynamic and constituent (salinity and temperature) transport and then writes a hydrodynamic linkage file for the water quality model WASP7 code. This model linkage, from EFDC hydrodynamics to WASP7 water quality, has been applied on many USEPA Region 4 projects in support of TMDLs and has been well tested (Wool 2003).

WASP7 is the new version of WASP with many upgrades to the user's interface and the model's capabilities. The major upgrades to WASP have been the addition of multiple BOD components, addition of sediment diagenesis routines, and addition of periphyton routines. WASP is an enhanced Windows version of the USEPA Water Quality Analysis Simulation Program (WASP), nonetheless, uses the same algorithms to solve water quality problems as those used in the DOS version. WASP is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program.

## **2.1 EFDC Application to the Savannah River Estuary**

The EFDC model was developed to run for seven years – from January 1, 1997 through December 31, 2003. The model grid, which includes 931 horizontal cells, extends upstream to Clyo, Georgia (~ 61 miles from Fort Pulaski) and downstream to the Atlantic Ocean (~17 miles offshore from Fort Pulaski). The model also includes marsh cells, to simulate the extensive intra-tidal marsh areas in the system, increasing the number of total cells to 947. The man-made connections affecting the system were included in the model. These included McCoy Cut, Rifle Cut, Drakie's Cut, New Cut as closed, and the sill of the Tide Gate.

Figure 2-1 shows the grid, while Figure 2-2 shows a closer view of the upper estuary. The Savannah Harbor EFDC model was calibrated with graphical time series comparisons (qualitative) and statistical calculations (quantitative). The statistical calculations included percentiles at 5% intervals. It included: water surface elevation, currents, flow, temperature, and salinity.

The calibration objectives for the hydrodynamic model were to appropriately represent the transport processes by propagating momentum and energy through the system based upon freshwater inflow from the Savannah River and tidal energy from the Atlantic Ocean. Since vertical stratification plays a major role in the water quality of the lower harbor area, it was imperative to capture the effect of tides and fresh water flows on salinity and temperature over the appropriate spatial and temporal scales. The primary objective was to simulate the salinity and temperature stratification events and to demonstrate that the duration and magnitude of the events were appropriately represented in the model. The calibration period was the summer of 1999. The confirmation period was the summer of 1997. Long-term United States Geological Survey (USGS) data was also used for confirmation. The two summer periods were both low-flow conditions with several spring/neap tide events occurring throughout the period.

The model calibration and validation results are presented in the report "Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project", January of 2006, prepared by Tetra Tech, Inc. for the USACE Savannah District.

Kinetic Analysis Corporation (KAC) performed a sensitivity/uncertainty analysis to quantify the sensitivity of the model simulations to uncertainty in values of model input data or calibration parameters. The results are presented in the January 2006 report as an appendix.

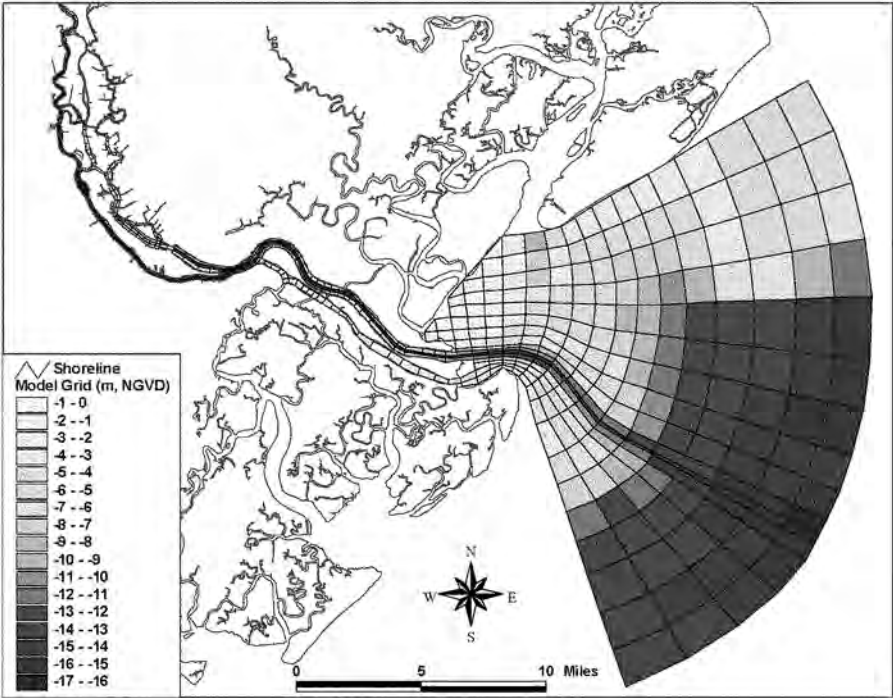


Figure 2-1 Model Grid and Bathymetry

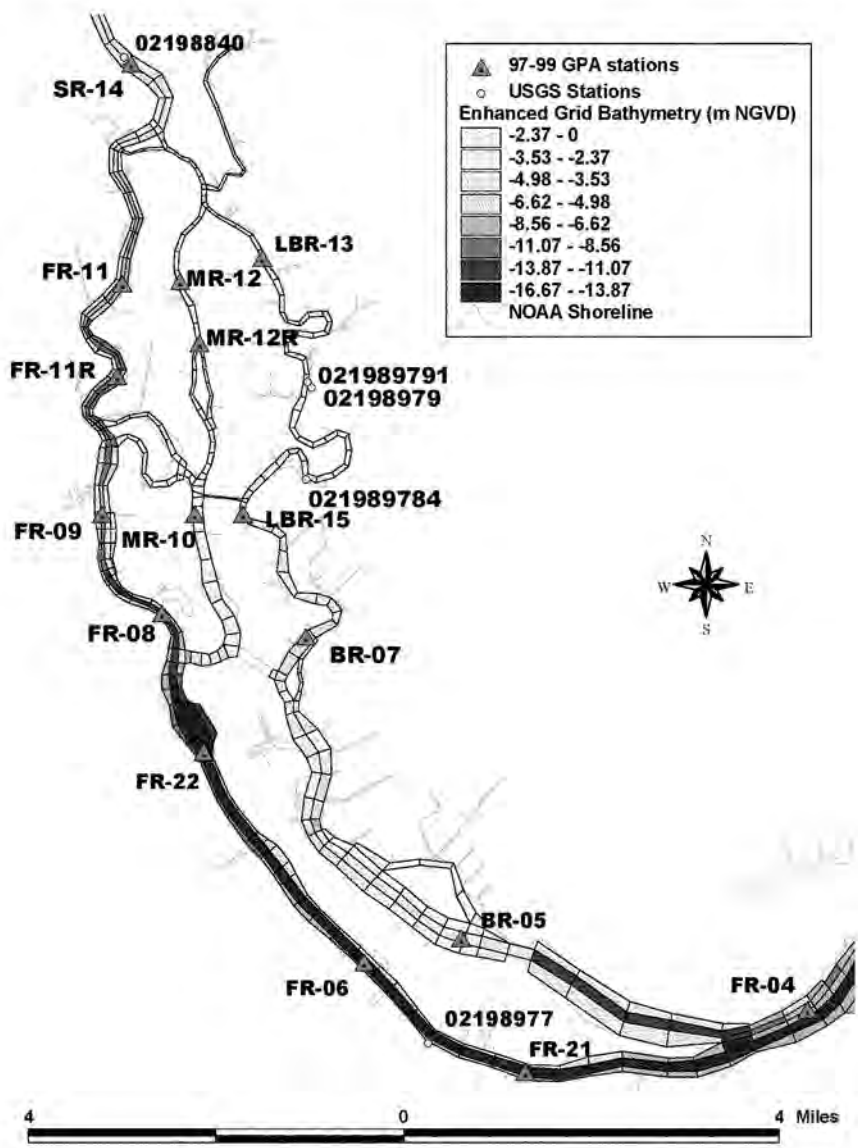


Figure 2-2 Model Grid and Bathymetry in the Upper Estuary

## **2.2 WASP Application to the Savannah River Estuary**

The water quality model incorporated oxygen dynamics, including: reaeration, sediment oxygen demand (SOD), carbonaceous Biochemical Oxygen Demand (CBOD) and uptake, and Nitrogenous Biochemical Oxygen Demand (NBOD) and uptake. Since there is limited algal activity or primary production in the harbor, EPA Region 4 determined that nutrients were not a significant issue and they were not included in the water quality modeling scenarios.

The EFDC hydrodynamic model provides WASP with the flows between cells, the flows between cells and boundaries, cell volume, salinity, and temperature. This information is incorporated into the WASP model through the hydrodynamic linkage file.

The calibration was performed using the summer 1999 dataset. The WASP model was run from July 21, 1999 to October 13, 1999 with a 10-day spin up time. The measured values from the data collected during the 1999 summer survey were used for calibration of the WASP water quality model. Specifically, dissolved oxygen, BOD, and ammonia data were used for the calibration.

The time period for the WASP model confirmation was from July 5, 1997 through October 13, 1997. In addition to the 1999 summer data collection, the 1997 summer data collection represented the most recent dissolved oxygen and water chemistry data for the system.

Model calibration and validation results, as well as the sensitivity analysis for the water quality model, are also presented in the January 2006 report (Tetra Tech 2006a).

## **2.3 An Approach to Evaluation of Deepening Impacts and Mitigation Measures**

The results of simulations that were performed under the project's Design of Dissolved Oxygen Improvement Systems in Savannah Harbor, Tasks I and II (Tetra Tech 2006b and 2006c) and their combination in Task III (Tetra Tech 2008) were used to develop the methodology to determine mitigation. This current work examines the impacts of the harbor deepening, Corps' mitigation plans, and the effects of oxygen injection system implementation based on average (August 1997) river flow conditions. The 2006 report identified average river flows as requiring more supplemental oxygen to meet harbor deepening mitigation requirements than do low river flow (August 1999) conditions (Tetra Tech 2006b and 2006c).

Figure 2-3 shows 27 spatial zones that delineate the estuary's simulated area. The zones cover the estuary area that can be affected by the harbor deepening. There are 11 zones for Front River (FR), 6 zones for Middle River (MR), 3 zones for Back River (BR), 3 zones for Little Back River (LBR), 2 zones for South Channel (SH), 1 zone for Steamboat River (StbR), and 1 zone for Savannah River (SR). The grid coordinates (I, J) zone boundaries are presented in Table 2-1.

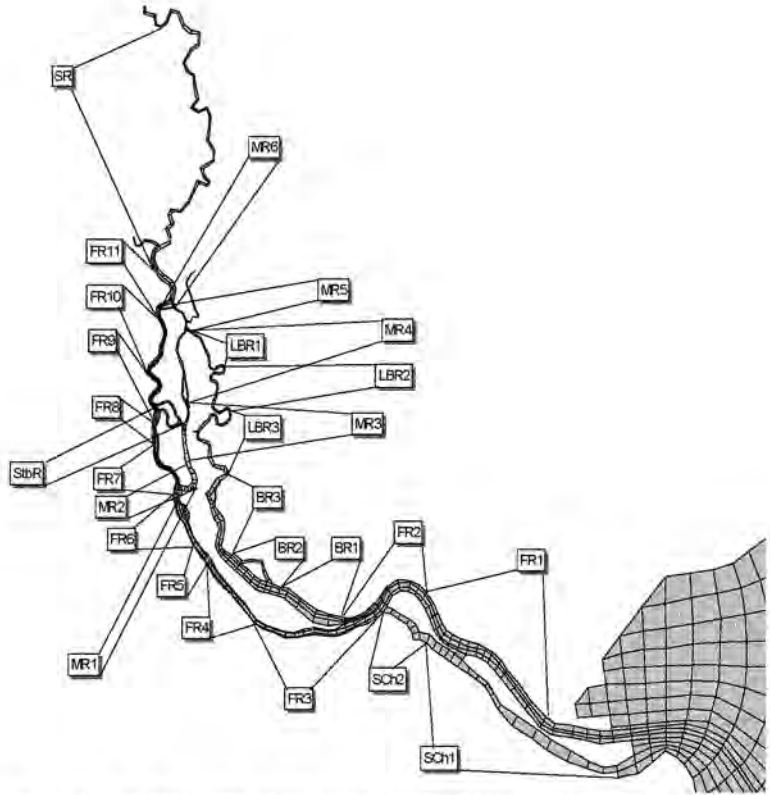


Figure 2-3 Zones' Delineation of Savannah Estuary Computational Grid

Table 2-1 Grid Coordinates and Volumes of Delineating Zones

| Zone # | Zone Name | Grid Coordinates |       |       |       | Volume km3*1000 | Relative Volume (%) |
|--------|-----------|------------------|-------|-------|-------|-----------------|---------------------|
|        |           | I beg            | J beg | I end | J end |                 |                     |
| 1      | FR1       | 13               | 26    | 17    | 40    | 54.816          | 23.94               |
| 2      | FR2       | 13               | 41    | 17    | 52    | 37.067          | 16.19               |
| 3      | FR3       | 13               | 53    | 17    | 59    | 15.172          | 6.63                |
| 4      | FR4       | 13               | 60    | 17    | 66    | 10.517          | 4.59                |
| 5      | FR5       | 13               | 67    | 17    | 72    | 7.066           | 3.09                |
| 6      | FR6       | 13               | 73    | 17    | 80    | 13.481          | 5.89                |
| 7      | FR7       | 13               | 81    | 17    | 93    | 6.352           | 2.77                |
| 8      | FR8       | 13               | 94    | 17    | 97    | 2.429           | 1.06                |
| 9      | FR9       | 13               | 98    | 15    | 111   | 5.624           | 2.46                |
| 10     | FR10      | 13               | 112   | 15    | 120   | 4.39            | 1.92                |
| 11     | FR11      | 13               | 121   | 14    | 127   | 3.455           | 1.51                |
| 12     | MR1       | 18               | 82    | 21    | 82    | 0.714           | 0.31                |
| 13     | MR2       | 21               | 83    | 21    | 86    | 0.967           | 0.42                |
| 14     | MR3       | 26               | 94    | 26    | 104   | 1.237           | 0.54                |
| 15     | MR4       | 26               | 105   | 26    | 122   | 0.951           | 0.42                |
| 16     | MR5       | 15               | 123   | 26    | 123   | 0.294           | 0.13                |
| 17     | MR6       | 20               | 118   | 20    | 119   | 0.029           | 0.01                |
| 18     | LBR1      | 27               | 123   | 38    | 123   | 0.401           | 0.18                |
| 19     | LBR2      | 39               | 106   | 39    | 123   | 0.805           | 0.35                |
| 20     | LBR3      | 30               | 86    | 30    | 109   | 2.766           | 1.21                |
| 21     | BR1       | 30               | 59    | 34    | 63    | 8.16            | 3.56                |
| 22     | BR2       | 30               | 64    | 34    | 70    | 4.988           | 2.18                |
| 23     | BR3       | 30               | 71    | 32    | 85    | 5.572           | 2.43                |
| 24     | SCh1      | 9                | 20    | 11    | 38    | 24.384          | 10.65               |
| 25     | SCh2      | 7                | 45    | 12    | 46    | 4.761           | 2.08                |
| 26     | SR        | 13               | 128   | 15    | 166   | 11.728          | 5.12                |
| 27     | StbR      | 16               | 99    | 25    | 101   | 0.833           | 0.36                |

The model's postprocessor is described in Appendix D. The postprocessor outputs information for the following harbor's spatial objects:

- Critical Cell – cell with lowest D.O. concentrations during specified simulation period
- Critical Segment – an assemblage of cross section cells located at the critical cell's j-coordinate
- Zone – an assemblage of cells that are limited by specified horizontal and vertical boundaries

The postprocessor outputs allow evaluation of the impact and mitigation effects by:

- Comparing critical cells' D.O. concentrations for existing and project scenarios
- Comparing zones' volume-weighted D.O. concentrations for existing and project scenarios
- Calculating the percentage of water volume with the projected D.O. concentration that do not meet the existing bathymetry D.O. concentrations during the selected simulation periods

The basic criteria for assessing the success of mitigation measures was proposed by the USACE Savannah District based on results of numerous meetings and discussions with federal and local environmental agencies. The criteria require 97% of the estuary waters have D.O. concentrations equal or higher than the concentrations at existing (pre-project) conditions.

The selection of vertical boundaries of zones is the important factor of mitigation success calculations. The one boundary layer (1BL) and a mean of three boundary layers (3BL) criteria were selected and applied for the project. The 1BL is just the bottom layer and the 3BL is the three bottom layers of the model.

### 3.0 MITIGATION PLANS FOR SALINITY AND WETLANDS

The USACE Savannah District used the EFDC model to determine the appropriate measures to mitigate for salinity and wetland impacts. Based on analysis of the model output, the flow-altering mitigation plans that were found to be the most effective at reducing salinity impacts and protecting fresh water tidal marshes are Plan 6A for the 48-, 47-, 46-, and 45-foot channel depths and 6B for the 44-foot channel depth. Although the plans do not fully mitigate for all impacts to the estuary, they are expected to provide substantial benefits to the fresh water marsh ecosystems adjacent to the Back and Little Back Rivers.

Plan 6B is the proposed flow-altering mitigation plan for the 44-foot channel depth. The features of this plan include a diversion structure on Front River, closure of the lower (western) arm at McCoy Cut, closure of Rifle Cut, filling of the Sediment Basin, and removal of the tide gate abutments and piers. This plan provides potential for additional fresh water flows to enter the Back River System at McCoy Cut, without exiting through the lower (western) arm, and flow downstream through Middle, Back, and Little Back Rivers. It also has features that will limit saltwater intrusion to the Back River area through the sediment basin and Rifle Cut.

Plan 6A is the proposed mitigation plan for the 45-, 46-, 47-, and 48-foot channel depths. This plan includes all the features of Plan 6B and one additional feature, channel deepening on McCoy Cut, upper Middle, and Little Back Rivers. This additional feature in combination with the features in Plan 6B maximizes the potential for additional fresh water flows to enter the Back River System at McCoy Cut and flow downstream through Middle, Back, and Little Back Rivers.

Plan 6A includes the enlarged McCoy Cut only to the junction of Middle and Little Back Rivers. Plan 6B includes Plan 6A plus extending the enlargement 1,700 feet downstream of the junction of the two rivers. Figures 3-1 and 3-2 were provided by the USACE Savannah District and depict the different features for Plan 6A and 6B, respectively.



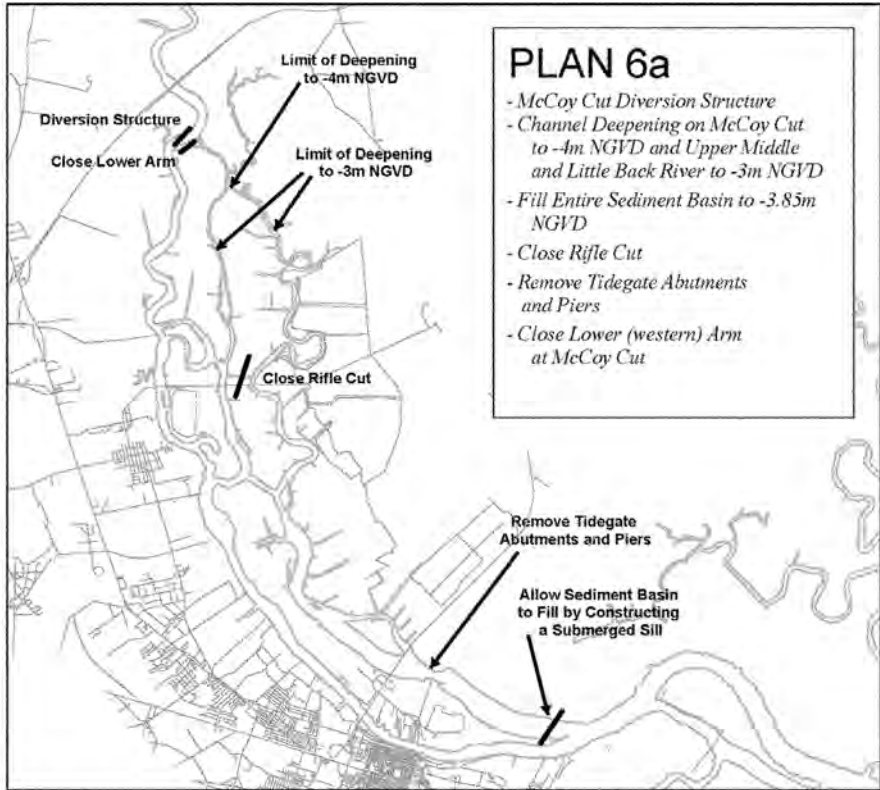


Figure 3-1 Mitigation Plan 6A (courtesy of the USACE Savannah District)

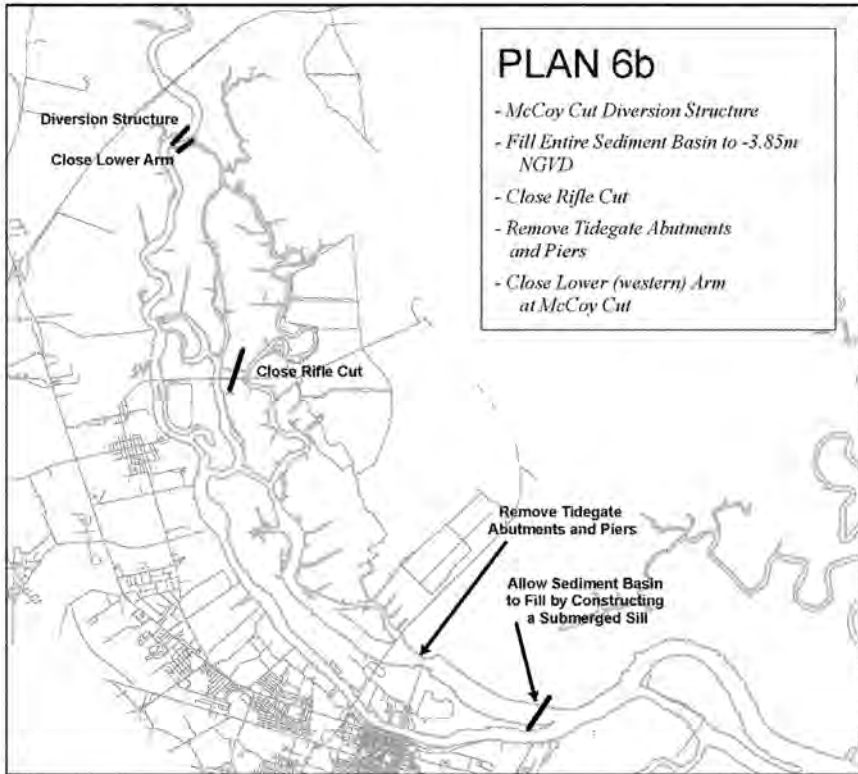


Figure 3-2 Mitigation Plan 6B (courtesy of the USACE Savannah District)

### 3.1 Impact of alternative deepening and mitigation plans on D.O. regime

Results of D.O. delta that were calculated by subtraction of existing bathymetry scenario outputs from the proposed mitigation plans alternative scenarios are presented in Table 3-1 and Appendix A.

Table 3-1 shows the percentage of water volumes where D.O. is not adversely affected by the proposed harbor deepening. The tables and figures presented in Appendix A allow identification of the harbor areas that are most affected by the deepening. These are zones F7, FR8, FR11, MR1, BR1, BR2, BR3, and LBR3 for mitigation plan 6A, and zones FR8, FR11, MR1, MR5, BR1, BR2, BR3, and LBR3 for mitigation plan 6B.

Such identification helps in selection of projected locations of components of the Oxygen Injection System.

Table 3-1 Volume of the harbor's water that was mitigated by plans 6A and 6B

| Scenario Description | Injection kg/day | Volume mitigation (%) for the percentiles |      |      |      |
|----------------------|------------------|-------------------------------------------|------|------|------|
|                      |                  | 5%                                        | 10%  | 25%  | 50%  |
| Plan 6A              |                  |                                           |      |      |      |
| 6 ft deepening       | 0                | 68.1                                      | 73   | 68.8 | 43.8 |
| Plan 6A              |                  |                                           |      |      |      |
| 5 ft deepening       | 0                | 71                                        | 74.2 | 69.5 | 58.5 |
| Plan 6A              |                  |                                           |      |      |      |
| 4 ft deepening       | 0                | 71.2                                      | 73.4 | 72.9 | 10.4 |
| Plan 6A              |                  |                                           |      |      |      |
| 3 ft deepening       | 0                | 73.3                                      | 75.4 | 75.2 | 69.7 |
| Plan 6B              |                  |                                           |      |      |      |
| 2 ft deepening       | 0                | 65.1                                      | 68.7 | 63.1 | 68.4 |

#### 4.0 OXYGEN INJECTION TECHNOLOGY

In order to inject oxygen into the system and to mitigate dissolved oxygen concentrations in the Savannah River Estuary that are below the standard, the technology developed by Dr. Richard Speece was used for design purposes. Dr. Speece invented the Speece Cone, a device originally used to add oxygen to the bottom of lakes to enhance downstream fisheries.

ECO2 SuperOxygenation systems ([www.eco2tech.com](http://www.eco2tech.com)) for water and wastewater treatment are designed and produced by Eco-Oxygen Technologies, LLC, an independent company headquartered in Indianapolis, Indiana.

The ECO2 SuperOxygenation method is a simple process based upon the scientific principle of Henry's Law. No chemicals and no moving parts other than standard municipal wastewater pumps are used. The result is a robust, reliable, economically competitive, and environmentally friendly technology.

This technology is appropriate when dissolved oxygen standards in the river are not attained, even if the industrial and municipal dischargers use the most advanced effluent treatments available. By superoxygenating directly to the river, water quality standards can be reached or maintained (Speece 2004).

This technology pulls a small sidestream of water from the river, superoxygenates it (using pure oxygen) and dilutes it back in the main river to satisfy dissolved oxygen deficiencies without treating the entire river. The sidestream is superoxygenated to achieve concentrations of 40 to 140 mg/L. Contrary to popular misconception, these high dissolved oxygen concentrations do not spontaneously effervesce, but can be kept in solution.

Cost comparisons with other traditional methods of oxygenation favor the use of this technology. Because pure oxygen and smaller sidestream flows used, less civil works and energy consumption are required than generally needed for aeration. Because the technology facilitates long residence times of gaseous oxygen in the oxygen transfer reactor, oxygen absorption efficiencies of 90 to 98% can be achieved.

The oxygen being dissolved can be supplied to the ECO 2 SuperOxygenation system in two ways:

1. Onsite oxygen generation either by Pulse Swing Absorption (PSA) or Vacuum Swing Absorption (VSA). Oxygen generation is a mature technology that has been used for decades and is widely used for wastewater treatment, medical facilities, and manufacturing. Oxygen generators operate by passing an air stream through a molecular sieve, which traps the nitrogen and discharges high purity oxygen for use. The nitrogen is then discharged into the atmosphere. The advantage to generating oxygen onsite is that oxygen is generated as it is being used, so there is no onsite bulk oxygen storage and it produces oxygen as a gas, not liquid. This eliminates issues centered on bulk liquid oxygen storage and truck delivery.
2. Bulk liquid oxygen (LOX). Bulk Liquid Oxygen is also widely used at wastewater treatment plants, manufacturing facilities and most noticeable medical hospitals. LOX systems are provided by a third party vendor that services, monitors, and delivers oxygen. LOX systems are comprised of a bulk oxygen storage tank and an evaporator. Liquid oxygen is trucked to the site and stored in the bulk oxygen tank. The liquid oxygen is piped through an evaporator that changes the liquid oxygen to gaseous oxygen.

High purity oxygen has been injected in water bodies in the past by various methods, such as pressurized sidestream, venturi aspirator, or turbine mixers, but inefficiently. The Downflow Bubble Contact Oxygenation equipment (Speece Cone) combines high oxygen absorption efficiency (>90%) with low unit energy consumption (<400 kwhr/ton D.O.), producing a superoxygenated discharge of >70 mg/L of D.O. The system can be placed out of the river channel without disrupting the water body, unlike aerators, or scouring the bottom.

Figure 4-1 shows a Speece Cone being installed at Newman Lake near Spokane, Washington. This cone was designed to add 3,300 pounds of oxygen per day (lbs/day) to a side stream of 13 million gallons per day (MGD) withdrawn from the hypolimnion of the lake.

Figure 4-2 shows a pictured of the Georgia Ports Authority (GPA) demonstration project managed by MACTEC. The results of the study are in the "Savannah Harbor Reoxygenation Demonstration Project, Savannah, Georgia" (MACTEC 2008) and, in summary, improve the dissolved oxygen levels in the mid-channel, average low-tide by about 0.6 mg/L along the three-mile-long target segment.

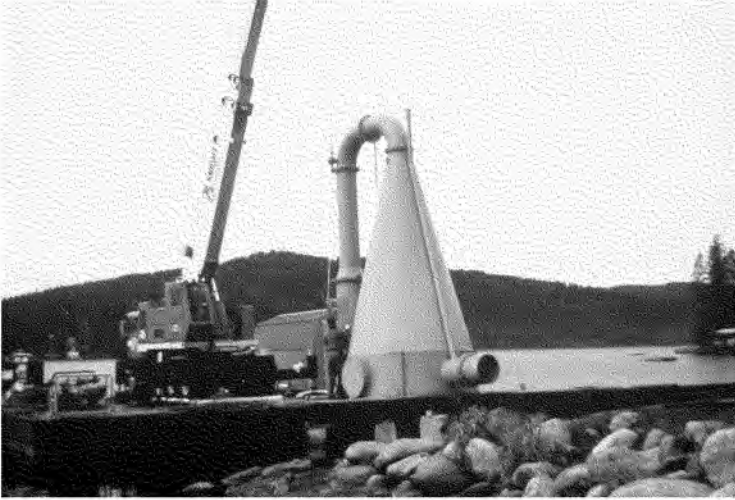


Figure 4-1      Speece Cone Being Installed in Newman Lake (from [www.eco2tech.com](http://www.eco2tech.com))



Figure 4-2      Summer 2007 GPA Demonstration Project (MACTEC, 2008)

## 5.0 INJECTION QUANTITIES AND LOCATIONS

The SHEP model was used to determine the optimal quantities and locations of the oxygen injection facilities needed to mitigate for harbor deepening impact on dissolved oxygen. The problems with selection of optimal locations are complicated by limited availability of potential injection sites with easy transport and access.

### 5.1 Injection for Harbor Deepening Mitigation (IP site)

The USACE proposed the site on Hutchinson Island (near the International Paper (IP) aeration lagoon) as an oxygen injection facility for discharging oxygen into Front and Back Rivers. The results of D.O. mitigation for 6 ft deepening (Plan 6A) are presented in Table 5-1. The scenarios labeled m1 through m4 in Table 5-1 are different magnitudes of the 1BL (bottom layer only) criteria.

Table 5-1 Oxygen loads and mitigation results for IP facilities: 1BL criteria

| Scenario | Cell Location | Coordinates | Injection | Sum      | Mitigation (%) for the percentiles |      |      |      |
|----------|---------------|-------------|-----------|----------|------------------------------------|------|------|------|
|          |               | (I, J)      | (kg/day)  | (kg/day) | 5%                                 | 10%  | 25%  | 50%  |
| m1       | IP            | FR (14,66)  | 30,000    | 37,000   | 89.8                               | 90.4 | 89.8 | 89.6 |
|          | IP            | BR (31,70)  | 7,000     |          |                                    |      |      |      |
| m2       | IP            | FR (14,66)  | 40,000    | 57,000   | 91                                 | 91.7 | 90.9 | 91.7 |
|          | IP            | BR (31,70)  | 17,000    |          |                                    |      |      |      |
| m3       | IP            | FR (14,66)  | 50,000    | 77,000   | 91.8                               | 92.8 | 92.4 | 92.5 |
|          | IP            | BR (31,70)  | 27,000    |          |                                    |      |      |      |
| m4       | IP            | FR (14,66)  | 80,000    | 140,000  | 93.3                               | 93.9 | 93.7 | 93.6 |
|          | IP            | BR (31,70)  | 60,000    |          |                                    |      |      |      |

The results of simulations under scenarios m1, m2, m3, and m4 demonstrate an inability of the Oxygen Injection Systems located only at the IP site to achieve the required 97% mitigation success criteria. So the IP Front and Back River injection sites alone do not mitigate all of harbor deepening impacts.

### 5.2 Injection for Harbor Deepening Mitigation (IP and GP sites)

The specifics of water circulation in Savannah River Estuary make oxygen discharge upstream of Savannah River very important. The Georgia Pacific (GP) site has high potential as an addition to the IP location for a combined Oxygen Injection System. Table 5-2 shows the results of D.O. mitigation for alternative deepening and 1BL criteria of success for locations near IP and GP.

Comparisons of results of Tables 5-1 and 5-2 demonstrate strong effect of upstream oxygen injection (GP) for FR and LBR zones. Such effect was not achievable by simply increasing of loads at the IP facility.

The Corps met with federal and state environmental agencies in February 2010 to discuss Tetra Tech's ongoing redesign of the oxygen injection systems. The agencies agreed that an upstream location appeared to be needed (in addition to the mid-harbor IP location) to meet the mitigation goals. The agencies agreed that the analysis could examine the effects in the lower half of the water column (bottom 3 layers of the model grid) rather than the bottom grid layer. D.O. generally decreases with channel depth, so analysis of conditions at the river bottom would represent worst-case conditions. Analysis of

the bottom half of the water column would be more representative (but still somewhat conservative) of average conditions throughout the water column.

The results of simulations and assessment of D.O. improvement on the basis of the 3 bottom layer (3BL) criteria are presented in Table 5-3.

Table 5-2 Oxygen loads and mitigation results for IP and GP facilities: 1BL criteria

| Scenario Description     | D.O. Discharge Location | Cell (I,J,K) Coordinates | Load (kg/day) | Sum (kg/day) | Volume mitigation (%) for the percentiles |      |      |      |
|--------------------------|-------------------------|--------------------------|---------------|--------------|-------------------------------------------|------|------|------|
|                          |                         |                          |               |              | 5%                                        | 10%  | 25%  | 50%  |
| Plan 6A                  | IP (FR)                 | 14, 66, 6                | 10,000        | 27,000       | 98.4                                      | 98.6 | 98.4 | 97.1 |
| 6 ft deepening (GP+IP_5) | IP (BR)                 | 31,70, 6                 | 7,000         |              |                                           |      |      |      |
|                          | Georgia-Pacific         | 14, 171, 6               | 10,000        | 22,000       | 97.3                                      | 97.3 | 98.1 | 97.3 |
| Plan 6A                  | IP (FR)                 | 14, 66, 6                | 9,000         |              |                                           |      |      |      |
| 5 ft deepening (5F-7)    | IP (BR)                 | 31,70, 6                 | 3,000         |              |                                           |      |      |      |
|                          | Georgia-Pacific         | 14, 171, 6               | 10,000        |              |                                           |      |      |      |
| Plan 6A                  | IP (FR)                 | 14, 66, 6                | 6,000         | 19,000       | 97.5                                      | 97.3 | 97.3 | 97.4 |
| 4 ft deepening (4F-3)    | IP (BR)                 | 31,70, 6                 | 3,000         |              |                                           |      |      |      |
|                          | Georgia-Pacific         | 14, 171, 6               | 10,000        |              |                                           |      |      |      |
| Plan 6A                  | IP (FR)                 | 14, 66, 6                | 3,000         |              |                                           |      |      |      |
| 3 ft deepening (3F-13)   | IP (BR)                 | 31,70, 6                 | 3,000         | 18,000       | 97.1                                      | 98.2 | 98.5 | 98.8 |
|                          | Georgia-Pacific         | 14, 171, 6               | 12,000        |              |                                           |      |      |      |
| Plan 6B                  | IP (FR)                 | 14, 66, 6                | 6,000         | 19,000       | 97.2                                      | 97.4 | 97   | 97.8 |
| 2 ft deepening (2B-1)    | IP (BR)                 | 31,70, 6                 | 3,000         |              |                                           |      |      |      |
|                          | Georgia-Pacific         | 14, 171, 6               | 10,000        |              |                                           |      |      |      |

Table 5-3 Oxygen loads and mitigation results for IP and GP facilities: 3BL criteria

| Scenario Description       | D.O. Discharge Location | Cell (I,J,K) Coordinates | Load (kg/day) | Sum (kg/day) | Volume mitigation (%) for the percentiles |      |      |      |
|----------------------------|-------------------------|--------------------------|---------------|--------------|-------------------------------------------|------|------|------|
|                            |                         |                          |               |              | 5%                                        | 10%  | 25%  | 50%  |
| Plan 6A                    | IP (FR)                 | 14, 66, 6                | 7,000         | 18,000       | 97.9                                      | 97.8 | 98.1 | 97.3 |
| 6 ft deepening (GP+IP_13m) | IP (BR)                 | 31,70, 6                 | 2,000         |              |                                           |      |      |      |
|                            | Georgia-Pacific         | 14, 171, 6               | 9,000         | 16,000       | 98.2                                      | 97.5 | 97.9 | 97.3 |
| Plan 6A                    | IP (FR)                 | 14, 66, 6                | 3,000         |              |                                           |      |      |      |
| 5 ft deepening (5F-5m)     | IP (BR)                 | 31,70, 6                 | 2,000         |              |                                           |      |      |      |
|                            | Georgia-Pacific         | 14, 171, 6               | 11,000        |              |                                           |      |      |      |
| Plan 6A                    | IP (FR)                 | 14, 66, 6                | 2,000         | 14,000       | 97.6                                      | 97.2 | 97.4 | 97.7 |
| 4 ft deepening (4F-3m)     | IP (BR)                 | 31,70, 6                 | 2,000         |              |                                           |      |      |      |
|                            | Georgia-Pacific         | 14, 171, 6               | 10,000        |              |                                           |      |      |      |
| Plan 6A                    | IP (FR)                 | 14, 66, 6                | 1,000         | 13,000       | 98.1                                      | 97.4 | 97.7 | 98.5 |
| 3 ft deepening (3F-3m)     | IP (BR)                 | 31,70, 6                 | 2,000         |              |                                           |      |      |      |
|                            | Georgia-Pacific         | 14, 171, 6               | 10,000        |              |                                           |      |      |      |
| Plan 6B                    | IP (FR)                 | 14, 66, 6                | 1,000         | 15,000       | 97.2                                      | 97.3 | 97.6 | 97.8 |
| 2 ft deepening (2B-6m)     | IP (BR)                 | 31,70, 6                 | 4,000         |              |                                           |      |      |      |
|                            | Georgia-Pacific         | 14, 171, 6               | 10,000        |              |                                           |      |      |      |

Table 5-3 shows the percent of the water volume where D.O. is at least as high as in the pre-project condition. The tables that show mitigation effect of Table 5-3 scenarios for every zone D.O. average and D.O. concentrations for critical cells are presented in Appendix B. The figures in Appendix B display 50<sup>th</sup> percentile of D.O. delta (Project minus Existing scenarios).



Appendix C contains tables that demonstrate mitigation success (required for 5<sup>th</sup>, 10<sup>th</sup>, 25<sup>th</sup>, and 50<sup>th</sup> percentiles) for surface, middle, and bottom layers.

Table 5-4 displays depths and statistics of oxygen saturation using oxygen injection facilities near IP and GP. This information is necessary for the design of oxygen injection in the harbor using Speece supersaturating cones.

Table 5-4 D.O. Saturation (%) in locations of GP and IP facilities

| Scenario Description | D.O. Discharge Location | Cell (I,J,K) Coordinates | Depth (m) | D.O. Saturation (%) |         |         |
|----------------------|-------------------------|--------------------------|-----------|---------------------|---------|---------|
|                      |                         |                          |           | 10 %ile             | 50 %ile | 90 %ile |
| Plan 6A              | IP (FR)                 | 14, 66, 6                | 16.92     | 53                  | 56      | 60      |
| 6 ft deepening       | IP (BR)                 | 31,70, 6                 | 3.33      | 30                  | 38      | 49      |
| (GP+IP_13m)          | Georgia-Pacific         | 14, 171, 6               | 3.62      | 65                  | 74      | 80      |
| Plan 6A              | IP (FR)                 | 14, 66, 6                | 16.61     | 53                  | 56      | 61      |
| 5 ft deepening       | IP (BR)                 | 31,70, 6                 | 3.33      | 29                  | 36      | 48      |
| (5F-5m)              | Georgia-Pacific         | 14, 171, 6               | 3.62      | 65                  | 74      | 80      |
| Plan 6A              | IP (FR)                 | 14, 66, 6                | 16.31     | 53                  | 56      | 62      |
| 4 ft deepening       | IP (BR)                 | 31,70, 6                 | 3.33      | 28                  | 35      | 48      |
| (4F-3m)              | Georgia-Pacific         | 14, 171, 6               | 3.62      | 65                  | 74      | 80      |
| Plan 6A              | IP (FR)                 | 14, 66, 6                | 16        | 53                  | 56      | 63      |
| 3 ft deepening       | IP (BR)                 | 31,70, 6                 | 3.33      | 27                  | 35      | 48      |
| (3F-3m)              | Georgia-Pacific         | 14, 171, 6               | 3.62      | 65                  | 74      | 80      |
| Plan 6B              | IP (FR)                 | 14, 66, 6                | 15.7      | 52                  | 57      | 65      |
| 2 ft deepening       | IP (BR)                 | 31,70, 6                 | 3.33      | 19                  | 29      | 45      |
| (2B-6m)              | Georgia-Pacific         | 14, 171, 6               | 3.62      | 65                  | 74      | 80      |

The location of the injection facilities for mitigation of deepening impacts are shown in Figure 5-1. Figure 5-2 shows a close-up view of the IP Hutchinson Island location with injection sites on the Front and Back Rivers.





Figure 5-1 Location of Components of Dissolved Oxygen Injection System



Figure 5-2 Location at IP Hutchinson Island

## 6.0 NEAR-FIELD MODELING RESULTS

A mixing zone analysis was performed at each of the three locations to simulate the near-field results. A request was made by South Carolina DHEC to perform a similar mixing zone analysis to the one in the 2007 Demonstration Project report (Tetra Tech 2009). The analysis for the 2007 Demonstration Project showed a small plume and a relatively short mixing zone. DHEC desired this analysis to occur for the designed locations as well.

In order to predict the near-field plume dynamics so that accurate estimates of height of rise and fall and initial dilution can be calculated, near-field plume numerical descriptive models have to be used. One of the most widely used choices over the past several years have been Visual Plumes. Visual Plumes (VP) is a family of mixing zone models to simulate surface water jets and plumes for a range of temperature, depth, discharge buoyancy, and ambient velocity conditions.

The VP model is a Windows-based mixing zone modeling application designed to replace the DOS-based PLUMES program (Baumgartner et al. 1994). VP was developed by the USEPA and supports initial dilution models that simulate single and merging submerged plumes in arbitrarily stratified ambient flow. Predictions include dilution, rise and sink, diameter, and other plume variables. A more detailed description of the VP model is included in Appendix E of the 2007 injection modeling report (Tetra Tech 2009) and can be viewed at <http://www.epa.gov/ceampub/swater/vplume/>. There are presently five recommended models in VP: DKHW, NRFIELD/FRFIELD, UM3, PDSW, and DOS PLUMES. For the present work the model UM3 was used. Figure 6-1 shows the output capabilities within the model after running scenarios (typical output).

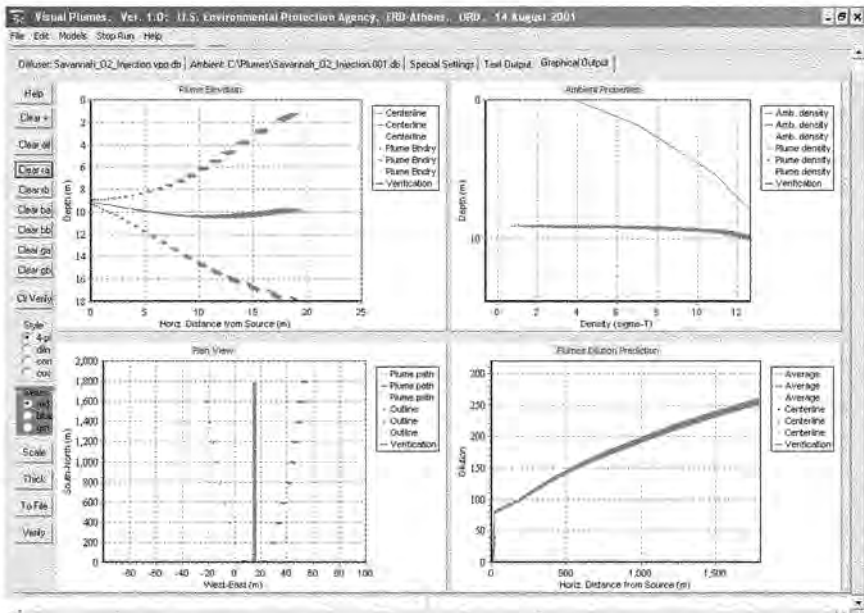


Figure 6-1 Typical Output using Visual Plumes Model

## 6.1 Plume Model

UM3 is an acronym for the three-dimensional Updated Merge (UM) model for simulating single and multi-port submerged discharges. UM3 is a Lagrangian model that features the projected-area entrainment (PAE) hypothesis. This established hypothesis quantifies forced entrainment, the rate at which mass is incorporated into the plume in the presence of current. In UM3, it is assumed that the plume is in steady state; in the Lagrangian formulation this implies that successive elements follow the same trajectory (Baumgartner et al. 1994). The plume envelope remains invariant while elements moving through it change their shape and position with time. To make UM three-dimensional, the PAE forced entrainment hypothesis has been generalized to include an entrainment term corresponding to the third-dimension: a cross-current term. As a result, single-port plumes are simulated as truly three-dimensional entities. Merged plumes are simulated less rigorously by distributing the cross-current entrainment over all plumes.

The average dilution factor,  $S_a$ , used in the UM model is the reciprocal of the volume fraction of effluent,  $v_e$ , contained in the diluted plume. An equivalent way of expressing this term is the ratio of effluent volume plus volume of ambient dilution water,  $v_a$ , to the effluent volume, as in the following equation:

$$S_a = 1 / (v_e / (v_e + v_a)) = (v_e + v_a) / v_e$$

Thus, in the region immediately outside the discharge orifice the volumetric dilution factor is very nearly 1. In some discussions of this term in other works, the factor is considered to be the ratio of the volume of ambient dilution water,  $v_a$ , to the volume of effluent discharged,  $v_e$ . In this definition, the volumetric dilution factor approaches zero near the orifice. Above a value of 30, the difference in the two definitions is progressively less than 3 %, an inconsequential amount for most regulatory purposes.

## 6.2 Near-Field Simulation Results

Tetra Tech used the three-dimensional EFDC Savannah Harbor model (Tetra Tech 2006a) to develop the flow and velocity field under which the simulations were performed. The three-dimensional model was run for the 1997 summer conditions based on earlier results that showed more oxygen is needed the summer of 1997 versus summer of 1999 due to slightly higher levels of flows (Tetra Tech 2006b, 2006c, and 2008). The ambient river time series of velocity, salinity, and temperature were obtained from the EFDC simulation results.

Other input information required by the near field model included the following:

- Physical setup of the discharge
- Physical schematization of the channel cross section at the injection location.

For each of the three locations, a VP model was developed and results presented in this section. The ambient conditions were developed by the EFDC model at each location by simulating the 6-foot deepening with mitigation Plan 6A.

For the effluent conditions of the effluent, the following parameters were assigned:

- Flow = 12,500 gallons per minute (gpm) for each cone
- Salinity = ambient conditions (intake = discharge)
- Temperature = ambient conditions (intake = discharge)
- Dissolved Oxygen = 140 mg/L (based on 2007 Demonstration Project)
- Depth = time series based water surface elevation (tides)

The salinity and temperature conditions for the effluent were set to the ambient conditions because we assumed the intake and discharge depth were equal. In the 2007 Demonstration Project, the intake was 10 feet below the surface and the discharge was 30 feet below the surface. The modeling of the Demonstration Project showed that the mixing zone of the plume was short (~ 60 feet) and was not buoyant because of the short distance. For the purposes of this design report, we assumed the intake and discharge depths would be the same depth but separated by a horizontal distance of 600 feet.

Ambient conditions were based on the following parameters:

- Salinity = time series from EFDC model
- Temperature = time series from EFDC model
- Dissolved Oxygen = time series from EFDC model
- Velocity = time series from EFDC model

Pipe conditions were based on the following parameters:

- Diameter = 18 inches
- Angle = varies
- Port Depth = varies
- Number of Ports = one
- Port Spacing (intake to effluent) = minimum of 600 feet

Table 6-1 summarizes the details of each of the three effluent designs and Figures 6-2 through 6-4 show the vertical mixing zone results for all three locations.

Table 6-1 Design parameters for each of the three locations

| Location          | Effluent Flow (MGD) | Effluent DO (mg/L) | Port Elevation* (m) | Pipe Diameter (inches) | Horizontal Angle (degrees) | Vertical Angle (degrees) |
|-------------------|---------------------|--------------------|---------------------|------------------------|----------------------------|--------------------------|
| Front River IP    | 108                 | 140                | 2                   | 18                     | 0                          | 20                       |
| Back River IP     | 72                  | 140                | 1                   | 18                     | 0                          | 0                        |
| Savannah River GP | 108                 | 140                | 1                   | 18                     | 0                          | 0                        |

\* Port Elevation is the distance from the bottom of the channel to the effluent pipe, so it is measured from the bottom.

At all three locations, the dissolved oxygen concentrations are close to background within 20 meters of the effluent discharge.

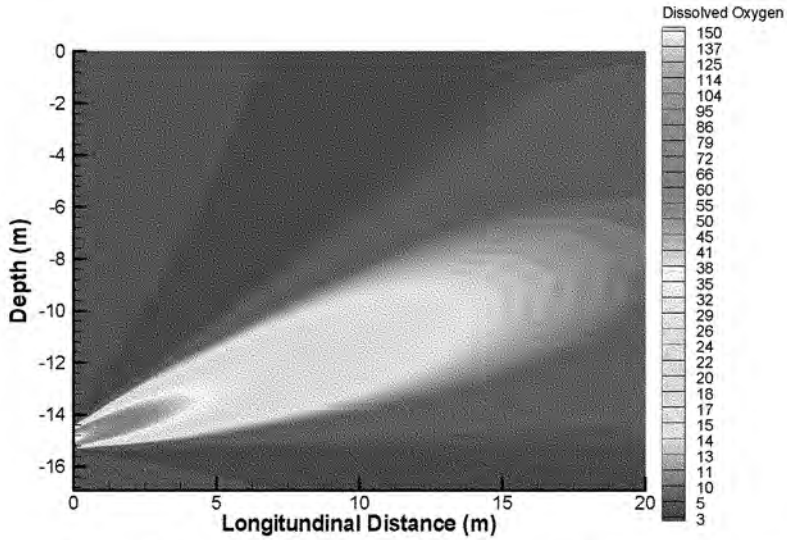


Figure 6-2 Visual Plume Model Results for Front River at International Paper

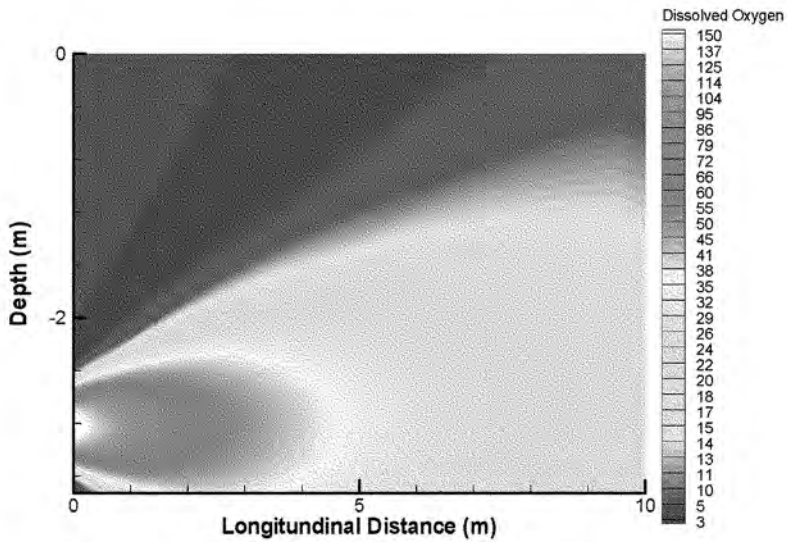


Figure 6-3 Visual Plume Model Results for Back River at International Paper

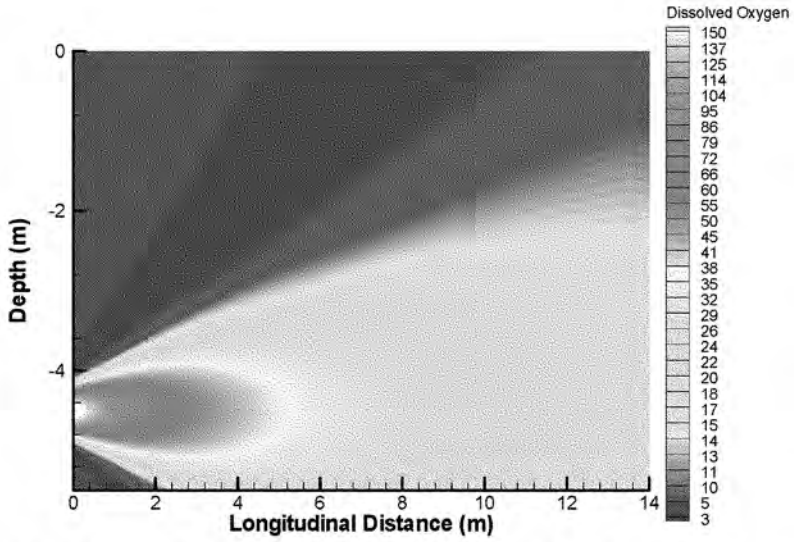


Figure 6-4 Visual Plume Model Results for Savannah River at Georgia Pacific

## 7.0 COST CONSIDERATIONS

This section describes cost considerations of installing and maintaining the oxygen injection systems. Capital costs include the purchasing, design, installing, and construction of the systems. Operating costs include the long-term maintenance of the systems. Tables 7-1 and 7-2 were developed to produce a cost estimate and summarize the installation and maintenance of one Speece Cone.

Table 7-1 Installation Cost Estimate of Speece Cone Land-Side Installation

| Description of Work                                              | Cost               |
|------------------------------------------------------------------|--------------------|
| One Speece Cone                                                  | \$748,474          |
| Design with Plans & Specs of grading, road, pad, house, & piping | \$225,000          |
| Construction (installation) of pumps, pipes, house, & cone       | \$342,500          |
| Oxygen generator & compressor                                    | \$170,000          |
| Subtotal                                                         | \$1,485,974        |
| Contingency (10%)                                                | \$148,597          |
| <b>TOTAL</b>                                                     | <b>\$1,634,571</b> |

Table 7-2 Maintenance Cost Estimate of Speece Cone Land-Side Installation

| Description of Work                                           | Cost            |
|---------------------------------------------------------------|-----------------|
| Operating and energy cost (includes electrical, O&M, license) | \$48,100        |
| Maintenance of cone (labor of field technicians)              | \$43,000        |
| <b>TOTAL</b>                                                  | <b>\$91,100</b> |

Therefore, the total cost of one cone is \$1,634,571 (including contingency) and \$91,100 per year in maintenance costs. Costs supplied by Eco2 (Eco2 2010) and previous MACTEC report (MACTEC 2008). See Appendix E for Eco2's quotation from March 17, 2010. These costs are based on generating oxygen on-site and supplying oxygen as needed. Therefore, no storage will be required.

Several assumptions were included and listed as the following:

- Above ground, land-side installation
- Oxygen generation on-site
- Speece Cone provides 5,000 lbs/day of oxygen
- Designed to consider 80% efficiency which is 4,000 lbs/day (regulators requested 80%)
- There would be a cost savings with more than one cone installed at a site (i.e., concrete pad, building, and piping may be overestimated)
- Design and construction considerations will be the elevation and soil conditions of the land, road and piping distances, and size of concrete pad
- Cones would run for approximately 180 days each year during the summer months

These costs do not include land procurement, utility installation, support building construction, or roadway construction as these are highly dependent on the sites selected. The support building would house equipment, control panels, oxygen generation equipment, and provide offseason storage of pumps, Speece Cone(s), and other equipment. Building costs will vary depending on the type (prefabricated, block, or concrete) and the finish required (some areas may have specific design requirements, i.e. brick, rock, etc.) for a specific location selected. These costs range from \$150,000 to \$300,000 or more. The below ground installation is more expensive because sheet piling and dewatering would be required during installation (MACTEC 2008).

## 8.0 CONCLUSIONS

The hydrodynamic and water quality models provided a tool to determine the amount of oxygen needed to mitigate for the deepening impacts on dissolved oxygen. With the expertise of Eco2, the designs were generated and summarized in Tables 8-1. The costs discussed in Section 7.0 were used to generate the cost at each of the three sites for each of the deepening scenarios. For each scenario, a mitigation plan (6A or 6B) was included.

Table 8-1 Summary of Dissolved Oxygen Loads and Cost (MITIGATION)

| Scenario        | Discharge Location | Load (kg/day) | Load (lb/day) | Cones | Cones (rounded) | Sum (kg/d) | Sum (lbs/d) | Cost at Each Site | Cost for Each Scenario |
|-----------------|--------------------|---------------|---------------|-------|-----------------|------------|-------------|-------------------|------------------------|
| 5 feet, Plan 6A | IP (FR)            | 7,000         | 15,432        | 3.86  | 4               | 18,000     | 39,683      | \$ 6,538,284      | \$ 16,345,710          |
|                 | IP (BR)            | 2,000         | 4,409         | 1.10  | 1               |            |             | \$ 1,634,571      |                        |
|                 | Georgia-Pacific    | 9,000         | 19,842        | 4.96  | 5               |            |             | \$ 8,172,855      |                        |
| 5 feet, Plan 6A | IP (FR)            | 3,000         | 6,614         | 1.65  | 2               | 16,000     | 35,274      | \$ 3,269,142      | \$ 14,711,139          |
|                 | IP (BR)            | 2,000         | 4,409         | 1.10  | 1               |            |             | \$ 1,634,571      |                        |
|                 | Georgia-Pacific    | 11,000        | 24,251        | 6.06  | 6               |            |             | \$ 9,807,426      |                        |
| 4 feet, Plan 6A | IP (FR)            | 2,000         | 4,409         | 1.10  | 1               | 14,000     | 30,865      | \$ 1,634,571      | \$ 13,076,568          |
|                 | IP (BR)            | 2,000         | 4,409         | 1.10  | 1               |            |             | \$ 1,634,571      |                        |
|                 | Georgia-Pacific    | 10,000        | 22,046        | 5.51  | 6               |            |             | \$ 9,807,426      |                        |
| 3 feet, Plan 6A | IP (FR)            | 1,000         | 2,205         | 0.55  | 1               | 13,000     | 28,660      | \$ 1,634,571      | \$ 13,076,568          |
|                 | IP (BR)            | 2,000         | 4,409         | 1.10  | 1               |            |             | \$ 1,634,571      |                        |
|                 | Georgia-Pacific    | 10,000        | 22,046        | 5.51  | 6               |            |             | \$ 9,807,426      |                        |
| 2 feet, Plan 6B | IP (FR)            | 1,000         | 2,205         | 0.55  | 1               | 15,000     | 33,069      | \$ 1,634,571      | \$ 14,711,139          |
|                 | IP (BR)            | 4,000         | 8,818         | 2.20  | 2               |            |             | \$ 3,269,142      |                        |
|                 | Georgia-Pacific    | 10,000        | 22,046        | 5.51  | 6               |            |             | \$ 9,807,426      |                        |

\*Three bottom layer criteria (3BL) were used to generate final results.

The costs for operating the dissolved oxygen injection systems are based on their continued operation for a period of 180 days per year. The operational costs are assumed to be uniform throughout that 180-day period. The operating costs would be less if the systems were operated for a shorter duration.



## 9.0 REFERENCES

- Baumgartner, D.J., W.E. Frick, and P.J.W. Roberts. 1994. Dilution models for effluent discharges (Third Edition). March 22, 1994. U.S. EPA. Washington, D.C. EPA Report #600/R-94/086. 189 pp.
- Eco2, March 17, 2010 "Preliminary Design & Budget Estimate" provided by David Clidence (Eco2) to Steven Davie (Tetra Tech)
- Hamrick, J. M., 1992: A Three-Dimensional Environment Fluid Dynamics Computer Code: Theoretical and Computational aspects. The College of William and Mary, Virginia Institute of Marine Science, Special Report 317, 63 p.
- MACTEC, 2005. "Identification and Screening Level Evaluation of Measures to Improve Dissolved Oxygen in the Savannah River Estuary" Savannah Harbor Expansion Project and Savannah Harbor Ecosystem Restoration Study – Chatham County, Georgia submitted to USACE Savannah District.
- MACTEC, 2008: Savannah Harbor Reoxygenation Demonstration Project, Savannah, Georgia. Prepared for the Georgia Ports Authority, January 8, 2008.
- Speece, R.E., 2004: The Role Of Superoxygenation In Achieving TMDL Requirements. R. E. Speece Ph.D., Centennial Professor Emeritus of Civil and Environmental Engineering Vanderbilt University, Nashville, TN and Board Member of ECO2. Indianapolis, Indiana.
- Tetra Tech, 2006a: Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project. Atlanta, Georgia.
- Tetra Tech, 2006b: Design of Dissolved Oxygen Improvement Systems in Savannah Harbor: Task I Report. Atlanta, Georgia.
- Tetra Tech, 2006c: Design of Dissolved Oxygen Improvement Systems in Savannah Harbor: Task II Report. Atlanta, Georgia.
- Tetra Tech, 2008: Final Report, Design of Dissolved Oxygen Improvement Systems in Savannah Harbor. Atlanta, Georgia.
- Tetra Tech, 2009: Modeling of GPA's Oxygen Injection Demonstration Project Savannah Harbor, Georgia. Atlanta, Georgia.
- Wool, T.A., S.R. Davie, and H.R. Rodriguez, 2003: "Development of a Three Dimensional Hydrodynamic and Water Quality Model to Support the TMDL Decision Process for the Neuse River Estuary, North Carolina." American Society of Engineers Journal of Water Resources Planning and Management.

**APPENDICES**

**APPENDIX A****DISSOLVED OXYGEN REGIME OF SAVANNAH ESTUARY:  
AUGUST 1997 (AVERAGE FLOW), ALTERNATIVE DEEPENING WITH  
MITIGATION PLANS 6A AND 6B, NO D.O. INJECTION****TABLES AND FIGURES**

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Table A-1 Delta (Project – Existing) D.O. Percentiles for Critical Cells: Plan 6a, 6 ft deepening, No injections

| Zone | Delta D.O. Percentile |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|------|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|      | 1%                    |       | 5%    |       | 10%   |       | 25%   |       | 50%   |       | 75%   |       | 90%   |       | 95%   |       | 99    |       |
|      | mg/l                  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     |
| FR1  | 0.02                  | 0.5   | 0.02  | 0.5   | 0.01  | 0.2   | 0     | 0.0   | -0.03 | -0.7  | -0.05 | -1.1  | -0.09 | -1.9  | -0.11 | -2.3  | -0.1  | -2.1  |
| FR2  | -0.06                 | -1.6  | -0.26 | -6.9  | -0.4  | -10.4 | 0.44  | 10.9  | 0.4   | 9.5   | -0.38 | -8.6  | -0.28 | -6.1  | -0.4  | -8.5  | -0.23 | -4.5  |
| FR3  | 0.12                  | 3.4   | 0.07  | 1.9   | 0.06  | 1.6   | 0.06  | 1.6   | -0.03 | -0.7  | 0.13  | -3.0  | -0.25 | -5.2  | -0.11 | -2.2  | -0.24 | -4.3  |
| FR4  | 0.12                  | 3.4   | 0.1   | 2.8   | 0.1   | 2.8   | 0.01  | 0.3   | -0.02 | -0.5  | -0.16 | -3.6  | -0.38 | -7.7  | -0.31 | -6.8  | -0.03 | -0.5  |
| FR5  | 0.12                  | 3.3   | 0.04  | 1.1   | -0.04 | -1.0  | -0.06 | -1.5  | -0.16 | -3.7  | 0.61  | -12.5 | -0.75 | -13.8 | -0.79 | -14.0 | -0.75 | -13.0 |
| FR6  | 0.03                  | 0.8   | 0.05  | 1.3   | 0     | 0.0   | 0.06  | -1.5  | -0.08 | -1.9  | 0.45  | -9.4  | 0.83  | -14.9 | 0.84  | -14.6 | -0.76 | -12.9 |
| FR7  | -0.18                 | -4.3  | -0.13 | -3.1  | -0.14 | -3.2  | -0.29 | -6.3  | -0.54 | -10.7 | -1.11 | -18.6 | -0.85 | -10.4 | -0.31 | -4.9  | -0.19 | -2.9  |
| FR8  | -0.3                  | -6.4  | -0.3  | -6.3  | -0.42 | -9.3  | -0.62 | -11.3 | -0.4  | -6.5  | -0.12 | -1.9  | -0.15 | -2.2  | -0.13 | -1.9  | -0.27 | -3.8  |
| FR9  | 0.24                  | 4.9   | 0.46  | 9.1   | 0.31  | 5.8   | 0.26  | 4.5   | 0.06  | 1.0   | 0.02  | 0.3   | 0.06  | 0.9   | 0.12  | 1.7   | 0.3   | 4.2   |
| FR10 | 0.39                  | 8.8   | 0.26  | 5.4   | 0.29  | 5.8   | 0.23  | 4.3   | -0.01 | -0.2  | -0.1  | -1.6  | -0.09 | -1.3  | -0.16 | -2.3  | -0.06 | -0.8  |
| FR11 | -1.46                 | -35.0 | -1.99 | -42.3 | -2.21 | -44.8 | -2.5  | -47.7 | -2.89 | -51.0 | -3.25 | -52.9 | -3.47 | -53.4 | -3.53 | -53.2 | -3.95 | -55.4 |
| MR1  | -0.23                 | -5.2  | -0.21 | -4.6  | -0.21 | -4.5  | -0.25 | -5.1  | -0.26 | -5.0  | -0.44 | -7.9  | -0.46 | -7.8  | -0.46 | -7.7  | -0.25 | -4.0  |
| MR2  | 0.19                  | 4.7   | 0.2   | 4.8   | 0.14  | 3.2   | 0.08  | 1.7   | -0.12 | -2.4  | -0.33 | -6.0  | -0.29 | -5.0  | -0.29 | -4.9  | -0.29 | -4.8  |
| MR3  | 0.49                  | 13.2  | 0.45  | 11.6  | 0.44  | 11.0  | 0.42  | 10.0  | 0.42  | 9.3   | 0.08  | 1.6   | -0.33 | -5.8  | -0.37 | -6.2  | -0.41 | -6.6  |
| MR4  | 0.46                  | 11.8  | 0.41  | 10.2  | 0.45  | 10.9  | 0.37  | 8.4   | 0.44  | 9.5   | 0.43  | 8.8   | 0.53  | 10.5  | 0.52  | 10.0  | 0.58  | 10.7  |
| MR5  | 0.71                  | 47.7  | 0.73  | 35.8  | 0.71  | 29.5  | 0.82  | 26.9  | 0.39  | 7.8   | -0.03 | -0.5  | -0.05 | -0.8  | -0.11 | -1.6  | -0.08 | -1.1  |
| MR6  | 0.53                  | 25.1  | 0.16  | 6.4   | -0.35 | -11.6 | -0.81 | -23.1 | -2.8  | -49.9 | -3.34 | -52.5 | -3.54 | -52.1 | -3.67 | -52.0 | -3.83 | -52.3 |
| LBR1 | 0.5                   | 14.0  | 0.47  | 10.8  | 0.36  | 7.4   | 0.37  | 7.2   | 0.37  | 6.8   | 0.46  | 8.2   | 0.35  | 5.9   | -0.38 | -6.2  | -0.23 | 3.6   |
| LBR2 | 0.6                   | 16.3  | 0.71  | 18.4  | 0.72  | 18.1  | 0.77  | 18.5  | 0.76  | 17.3  | 0.79  | 17.2  | 0.79  | 16.6  | 0.82  | 16.8  | 0.55  | 10.5  |
| LBR3 | -0.38                 | -13.1 | -0.62 | -18.9 | -0.67 | -19.3 | -0.68 | -17.9 | -0.65 | -16.5 | -0.7  | -16.1 | -0.91 | -19.2 | -1.08 | -21.6 | -1.18 | -22.5 |
| BR1  | -1.42                 | -41.2 | -0.86 | -24.4 | -0.43 | -12.0 | -0.09 | -2.3  | 0.25  | 6.2   | 0.39  | 9.2   | 0.25  | 5.5   | 0.23  | 5.0   | 0.27  | 5.8   |
| BR2  | -0.93                 | -36.5 | -0.88 | -30.3 | -0.81 | -27.1 | -0.67 | -20.7 | -0.4  | -11.6 | -0.07 | -1.9  | 0.09  | 2.3   | 0.09  | 2.3   | 0.11  | 2.7   |
| BR3  | -1.23                 | -40.6 | -1.23 | -37.7 | -1.3  | -37.8 | -1.32 | -36.5 | -1.23 | -32.5 | -0.93 | -23.5 | -0.61 | -16.0 | -0.55 | -13.3 | -0.43 | -10.1 |
| SCH1 | -0.15                 | -3.3  | -0.04 | -1.6  | 0.01  | 0.4   | 0.03  | 1.1   | 0.15  | 5.0   | 0.54  | 15.8  | 0.47  | 12.5  | 0.53  | 13.6  | 0.46  | 11.1  |
| SCH2 | -0.04                 | -1.1  | -0.11 | -2.8  | -0.1  | -2.5  | -0.02 | -0.5  | -0.05 | -1.2  | -0.06 | -1.3  | -0.07 | -1.5  | -0.08 | -1.7  | -0.13 | -2.7  |
| SR   | -0.01                 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  |
| StbR | -0.16                 | -4.2  | 0.09  | 2.1   | -0.04 | -0.9  | 0.03  | 0.6   | -0.07 | -1.2  | -0.19 | -3.1  | -0.19 | -2.9  | -0.25 | -3.8  | -0.22 | -3.2  |

Table A-2 Delta (Project – Existing) D.O. Percentiles for Critical Cells: Plan 6a, 5 ft deepening, No injections

| Zone | Delta D.O. Percentile |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|------|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|      | 1%                    |       | 5%    |       | 10%   |       | 25%   |       | 50%   |       | 75%   |       | 90%   |       | 95%   |       | 99    |       |
|      | mg/l                  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     |
| FR1  | 0.01                  | 0.3   | 0     | 0.0   | 0     | 0.0   | 0.02  | 0.5   | -0.04 | -0.9  | -0.04 | -0.9  | -0.07 | -1.5  | -0.1  | -2.1  | -0.09 | -1.9  |
| FR2  | -0.14                 | -3.8  | 0.2   | 5.3   | 0.36  | 9.9   | 0.44  | 10.9  | 0.39  | 9.2   | 0.38  | 8.6   | 0.3   | 6.5   | 0.41  | 8.7   | 0.23  | 4.5   |
| FR3  | 0.12                  | 3.4   | 0.07  | 1.9   | 0.06  | 1.6   | 0.04  | 1.0   | -0.01 | -0.2  | -0.07 | -1.6  | -0.2  | -4.2  | 0.02  | 0.4   | -0.13 | -2.3  |
| FR4  | -0.11                 | -3.1  | 0.1   | 2.8   | 0.08  | 2.2   | 0     | 0.0   | -0.04 | -1.0  | -0.2  | -4.5  | -0.36 | -7.3  | -0.29 | -5.5  | -0.03 | -0.5  |
| FR5  | 0.11                  | 3.0   | 0.04  | 1.1   | 0.01  | 0.3   | 0.03  | 0.7   | 0.13  | -3.0  | 0.51  | 10.4  | 0.59  | 10.9  | 0.56  | 8.8   | -0.5  | -8.7  |
| FR6  | 0.03                  | 0.8   | 0.07  | 1.9   | 0     | 0.0   | -0.05 | -1.2  | -0.07 | -1.6  | -0.4  | -8.4  | -0.71 | -12.7 | -0.62 | -10.7 | -0.57 | -9.6  |
| FR7  | 0.23                  | 5.5   | 0.28  | 6.6   | 0.32  | 7.4   | 0.28  | 6.1   | 0.42  | 8.3   | 0.06  | 0.8   | 0.05  | 0.8   | 0.19  | 3.0   | 0.63  | 9.7   |
| FR8  | -0.27                 | -5.8  | -0.26 | -5.4  | -0.38 | -7.5  | -0.54 | -9.8  | -0.27 | -4.4  | -0.06 | -0.9  | -0.11 | -1.6  | -0.12 | -1.8  | -0.23 | -3.2  |
| FR9  | 0.03                  | 0.6   | 0.29  | 5.8   | 0.15  | 2.8   | 0.25  | 4.4   | 0.1   | 1.6   | 0.09  | 1.4   | 0.17  | 2.5   | 0.18  | 2.8   | 0.17  | 2.4   |
| FR10 | 0.38                  | 8.8   | 0.26  | 5.4   | 0.28  | 5.7   | 0.23  | 4.3   | -0.02 | -0.3  | -0.11 | -1.7  | -0.08 | -1.2  | -0.16 | -2.3  | -0.08 | -0.8  |
| FR11 | -1.48                 | -35.0 | -1.99 | -42.3 | -2.21 | -44.8 | -2.5  | -47.7 | -2.89 | -51.0 | -3.25 | -52.9 | -3.47 | -53.4 | -3.53 | -53.2 | -3.95 | -55.4 |
| MR1  | -0.21                 | -4.8  | -0.19 | -4.2  | -0.19 | -4.1  | -0.23 | -4.7  | -0.22 | -4.3  | -0.42 | -7.5  | -0.42 | -7.1  | -0.34 | -5.7  | -0.23 | -3.7  |
| MR2  | 0.19                  | 4.7   | 0.21  | 5.1   | 0.16  | 3.7   | 0.09  | 1.9   | -0.09 | -1.6  | -0.29 | -5.2  | -0.25 | -4.3  | -0.22 | -3.7  | -0.25 | -4.1  |
| MR3  | 0.49                  | 13.2  | 0.47  | 12.1  | 0.44  | 11.0  | 0.45  | 10.7  | 0.42  | 9.3   | 0.12  | 2.4   | -0.3  | -5.3  | -0.33 | -5.6  | -0.36 | -5.8  |
| MR4  | 0.47                  | 12.1  | 0.42  | 10.4  | 0.47  | 11.4  | 0.38  | 8.7   | 0.45  | 9.8   | 0.41  | 8.4   | 0.53  | 10.5  | 0.51  | 9.8   | 0.58  | 10.7  |
| MR5  | -0.71                 | -47.7 | -0.74 | -36.3 | -0.71 | -29.5 | -0.81 | -26.6 | -0.39 | -7.8  | -0.04 | -0.8  | -0.04 | -0.6  | -0.11 | -1.6  | -0.08 | -1.1  |
| MR6  | 0.53                  | 25.1  | 0.16  | 6.4   | -0.35 | -11.6 | -0.81 | -23.1 | -2.8  | -49.9 | -3.34 | -52.5 | -3.54 | -52.1 | -3.67 | -52.0 | -3.83 | -52.3 |
| LBR1 | 0.49                  | 13.7  | 0.47  | 10.8  | 0.37  | 7.8   | 0.36  | 7.0   | 0.37  | 6.8   | 0.46  | 8.2   | 0.35  | 5.9   | 0.39  | 6.3   | 0.23  | 3.6   |
| LBR2 | 0.79                  | 21.4  | 0.71  | 18.4  | 0.72  | 18.1  | 0.76  | 18.3  | 0.75  | 17.1  | 0.78  | 17.0  | 0.79  | 16.6  | 0.8   | 16.4  | 0.55  | 10.5  |
| LBR3 | -0.35                 | -12.1 | -0.61 | -15.6 | -0.65 | -16.7 | -0.64 | -17.4 | -0.63 | -15.9 | -0.71 | -16.4 | -0.91 | -19.2 | -1.1  | -22.0 | -1.22 | -23.3 |
| BR1  | -1.53                 | -44.3 | -1.01 | -28.7 | -0.54 | -15.0 | -0.11 | -2.8  | 0.22  | 5.5   | 0.37  | 8.7   | 0.26  | 5.7   | 0.24  | 5.2   | 0.29  | 6.2   |
| BR2  | -0.96                 | -37.6 | -1.04 | -36.6 | -1.01 | -33.8 | -0.88 | -27.2 | -0.68 | -19.8 | -0.64 | -17.3 | -0.52 | -13.5 | -0.52 | -13.2 | -0.47 | -11.7 |
| BR3  | -1.31                 | -43.2 | -1.31 | -40.2 | -1.39 | -40.4 | -1.4  | -38.7 | -1.31 | -34.7 | -1.03 | -26.1 | -0.68 | -16.7 | -0.62 | -14.9 | -0.51 | -12.0 |
| SCH1 | -0.09                 | -3.8  | -0.1  | -3.9  | 0     | 0.0   | 0.08  | 2.8   | 0.04  | 1.3   | -0.13 | -3.8  | -0.13 | -3.4  | -0.11 | -2.8  | -0.23 | -5.6  |
| SCH2 | -0.06                 | -1.6  | -0.11 | -2.8  | -0.09 | -2.2  | -0.05 | -1.2  | -0.06 | -1.2  | -0.04 | -0.9  | -0.05 | -1.1  | -0.07 | -1.5  | -0.06 | -1.2  |
| SR   | -0.01                 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  |
| StbR | -0.09                 | -2.3  | 0.08  | 1.9   | 0.02  | 0.4   | 0.07  | 1.4   | -0.02 | -0.4  | -0.15 | -3.4  | -0.17 | -2.6  | -0.19 | -2.9  | -0.18 | -2.8  |

Table A-3 Delta (Project – Existing) D.O. Percentiles for Critical Cells: Plan 6a, 4 ft deepening, No injections

| Zone | Delta D.O. Percentile |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|------|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|      | 1%                    |       | 5%    |       | 10%   |       | 25%   |       | 50%   |       | 75%   |       | 90%   |       | 95%   |       | 99    |       |
|      | mg/l                  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     |
| FR1  | 0                     | 0.0   | -0.02 | -0.5  | -0.03 | -0.7  | -0.01 | -0.2  | -0.05 | -1.1  | -0.03 | -0.7  | -0.04 | -0.9  | -0.06 | -1.3  | -0.06 | -1.3  |
| FR2  | -0.15                 | -4.4  | 0.19  | 5.1   | 0.37  | 9.6   | 0.43  | 10.7  | 0.4   | 9.5   | 0.4   | 9.1   | 0.31  | 6.7   | 0.42  | 9.0   | 0.24  | 4.7   |
| FR3  | 0.1                   | 2.9   | 0.05  | 1.4   | 0.04  | 1.1   | 0.06  | 1.6   | 0     | 0.0   | -0.06 | -1.4  | -0.13 | -2.7  | 0.09  | 1.8   | -0.08 | -1.4  |
| FR4  | 0.09                  | 2.6   | 0.08  | 2.2   | 0.08  | 2.2   | 0.01  | 0.3   | -0.01 | -0.2  | -0.17 | -3.9  | -0.31 | -6.2  | -0.19 | -3.6  | -0.1  | -1.8  |
| FR5  | 0.1                   | 2.8   | 0.01  | 0.3   | -0.07 | -1.8  | -0.05 | -1.5  | -0.17 | -3.9  | -0.59 | -12.1 | -0.6  | -11.1 | -0.6  | -10.7 | -0.57 | -9.9  |
| FR6  | 0.05                  | 1.4   | 0.07  | 1.9   | 0.01  | 0.3   | -0.04 | -1.0  | -0.05 | -1.2  | -0.38 | -7.9  | -0.57 | -10.2 | -0.44 | -7.6  | -0.43 | -7.3  |
| FR7  | 0.51                  | 12.2  | 0.58  | 13.6  | 0.7   | 16.2  | 0.73  | 15.8  | 0.82  | 16.3  | 0.31  | 5.2   | 0.27  | 4.3   | 0.4   | 8.3   | 0.63  | 9.7   |
| FR8  | -0.22                 | -4.7  | -0.22 | -4.6  | -0.31 | -6.1  | -0.48 | -8.7  | -0.18 | -2.9  | -0.04 | -0.5  | -0.07 | -1.0  | -0.09 | -1.3  | -0.22 | -3.1  |
| FR9  | -0.28                 | -5.7  | -0.35 | -7.0  | -0.27 | -5.8  | -0.6  | -10.5 | 0.4   | 8.4   | 0.22  | 3.3   | -0.19 | -2.8  | -0.27 | -3.8  | -0.18 | -2.6  |
| FR10 | 0.38                  | 8.8   | 0.26  | 5.4   | 0.27  | 5.5   | 0.24  | 4.5   | -0.01 | -0.2  | -0.12 | -1.9  | -0.08 | -1.2  | -0.15 | -2.1  | -0.07 | -1.0  |
| FR11 | -1.46                 | -35.0 | -1.99 | -42.3 | -2.21 | -44.8 | -2.5  | -47.7 | -2.89 | -51.0 | -3.25 | -52.9 | -3.47 | -53.4 | -3.53 | -53.2 | -3.95 | -56.4 |
| MR1  | -0.17                 | -3.9  | -0.16 | -3.5  | -0.14 | -3.0  | -0.2  | -4.1  | -0.19 | -3.7  | -0.37 | -8.6  | -0.37 | -8.4  | -0.27 | -4.5  | -0.12 | -1.9  |
| MR2  | 0.21                  | 5.2   | 0.23  | 5.5   | 0.16  | 3.7   | 0.1   | 2.2   | -0.06 | -1.2  | -0.26 | -4.7  | -0.22 | -3.8  | -0.18 | -3.1  | -0.2  | -3.3  |
| MR3  | 0.52                  | 14.1  | 0.41  | 10.5  | 0.43  | 10.8  | 0.47  | 11.2  | 0.39  | 8.6   | 0.05  | 1.2   | -0.37 | -8.5  | -0.47 | -7.9  | -0.48 | -7.8  |
| MR4  | 0.47                  | 12.1  | 0.42  | 10.4  | 0.47  | 11.4  | 0.39  | 8.9   | 0.45  | 9.8   | 0.45  | 9.2   | 0.51  | 10.1  | 0.51  | 9.8   | 0.57  | 10.5  |
| MR5  | 0.71                  | 47.7  | 0.74  | 36.3  | 0.71  | 29.5  | 0.81  | 26.6  | 0.38  | 7.6   | -0.03 | -0.5  | -0.04 | -0.6  | -0.11 | -1.6  | -0.07 | -1.0  |
| MR6  | 0.53                  | 25.1  | 0.16  | 6.4   | -0.35 | -11.6 | -0.81 | -23.1 | -2.8  | -49.9 | -3.34 | -52.5 | -3.54 | -52.1 | -3.67 | -52.0 | -3.83 | -52.3 |
| LBR1 | -0.48                 | -12.9 | -0.48 | -10.6 | -0.38 | -8.0  | -0.56 | -7.0  | -0.37 | 6.8   | 0.48  | 8.2   | 0.35  | 5.9   | 0.39  | 6.3   | 0.21  | 3.2   |
| LBR2 | 0                     | 0.0   | 0.7   | 18.1  | 0.71  | 17.9  | 0.77  | 18.5  | 0.75  | 17.1  | 0.78  | 17.0  | 0.78  | 16.4  | 0.8   | 16.4  | 0.54  | 10.3  |
| LBR3 | -0.3                  | -10.4 | -0.6  | -18.3 | -0.63 | -18.2 | -0.62 | -16.8 | -0.62 | -15.7 | -0.7  | -16.1 | -0.92 | -19.5 | -1.1  | -22.0 | -1.2  | -22.9 |
| BR1  | -1.63                 | -47.2 | -1.18 | -30.5 | -0.61 | -17.0 | -0.18 | -4.1  | 0.21  | 5.2   | 0.38  | 9.0   | 0.26  | 5.7   | 0.24  | 5.2   | 0.29  | 6.2   |
| BR2  | -1.14                 | -44.7 | -1.05 | -37.0 | -1    | -33.4 | -0.82 | -35.3 | -0.51 | -14.8 | -0.15 | -4.1  | -0.02 | -0.5  | 0.05  | 1.5   | 0.13  | 3.2   |
| BR3  | -1.41                 | -46.5 | -1.41 | -43.3 | -1.45 | -42.2 | -1.46 | -40.3 | -1.37 | -36.2 | -1.13 | -28.6 | -0.74 | -18.1 | -0.66 | -15.9 | -0.59 | -13.9 |
| SCH1 | -0.11                 | -4.6  | -0.1  | -3.9  | 0.02  | 0.7   | 0.07  | 2.5   | 0.04  | 1.3   | -0.13 | -3.8  | -0.16 | -4.2  | -0.09 | -2.3  | -0.14 | -3.4  |
| SCH2 | -0.04                 | -1.1  | -0.05 | -1.3  | -0.06 | -1.5  | -0.05 | -1.2  | -0.06 | -1.4  | -0.07 | -1.6  | -0.06 | -1.3  | -0.06 | -1.3  | -0.05 | -1.0  |
| SR   | -0.01                 | -0.2  | 0     | 0.0   | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  |
| StbR | -0.02                 | -0.5  | 0.1   | 2.4   | 0.07  | 1.5   | 0.11  | 2.2   | -0.02 | -0.4  | -0.09 | -1.5  | -0.13 | -2.0  | -0.15 | -2.3  | -0.19 | -2.6  |

Table A-4 Delta (Project – Existing) D.O. Percentiles for Critical Cells: Plan 6a, 3 ft deepening, No injections

| Zone | Delta D.O. Percentile |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|------|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|      | 1%                    |       | 5%    |       | 10%   |       | 25%   |       | 50%   |       | 75%   |       | 90%   |       | 95%   |       | 99    |       |
|      | mg/l                  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     |
| FR1  | 0.01                  | 0.3   | -0.01 | -0.3  | -0.02 | -0.5  | -0.02 | -0.5  | -0.04 | -0.9  | -0.02 | -0.4  | -0.02 | -0.4  | -0.06 | -1.3  | -0.03 | -0.6  |
| FR2  | -0.15                 | -4.1  | 0.19  | 5.1   | 0.38  | 9.9   | 0.43  | 10.7  | 0.4   | 9.5   | 0.41  | 9.3   | 0.31  | 6.7   | 0.43  | 9.2   | 0.23  | 4.5   |
| FR3  | 0.1                   | 2.9   | 0.05  | 1.4   | 0.05  | 1.4   | 0.08  | 2.1   | 0.03  | 0.7   | 0.01  | 0.2   | -0.1  | -2.1  | 0.13  | 2.6   | -0.05 | -0.9  |
| FR4  | 0.1                   | 2.9   | 0.08  | 2.2   | 0.07  | 1.9   | 0.05  | 1.3   | 0.01  | 0.2   | -0.11 | -2.5  | -0.2  | -4.0  | -0.08 | -1.5  | 0.11  | 2.0   |
| FR5  | 0.1                   | 2.8   | 0.03  | 0.8   | -0.03 | -0.8  | -0.02 | -0.5  | -0.11 | -2.6  | -0.51 | -10.4 | -0.41 | -7.6  | -0.36 | -6.4  | -0.31 | -5.4  |
| FR6  | 0.07                  | 1.9   | 0.09  | 2.1   | 0.02  | 0.5   | 0     | 0.0   | -0.02 | -0.5  | -0.31 | -6.5  | -0.39 | -7.0  | -0.29 | -5.0  | -0.28 | -4.7  |
| FR7  | -0.11                 | -2.6  | 0.07  | 1.6   | 0.1   | 2.3   | 0.2   | 4.3   | 0.37  | 7.4   | 0.6   | 10.0  | 0.21  | 3.4   | 0.15  | 2.4   | 0.1   | 1.5   |
| FR8  | -0.19                 | -4.1  | -0.22 | -4.6  | -0.34 | -6.7  | -0.48 | -8.7  | -0.28 | -4.1  | -0.19 | -2.8  | -0.21 | -3.1  | -0.19 | -2.9  | -0.25 | -3.5  |
| FR9  | -0.23                 | -4.7  | -0.3  | -6.0  | -0.41 | -7.7  | -0.49 | -8.6  | -0.31 | -4.9  | 0.17  | 2.6   | -0.17 | -2.5  | -0.26 | -3.7  | -0.18 | -2.5  |
| FR10 | 0.38                  | 8.8   | 0.26  | 5.4   | 0.27  | 5.5   | 0.23  | 4.3   | -0.01 | -0.2  | -0.12 | -1.9  | -0.08 | -1.2  | -0.16 | -2.3  | -0.07 | -1.0  |
| FR11 | -1.46                 | -35.0 | -1.99 | -42.3 | -2.21 | -44.8 | -2.5  | -47.7 | -2.89 | -51.0 | -3.25 | -52.9 | -3.47 | -53.4 | -3.53 | -53.2 | -3.95 | -56.4 |
| MR1  | -0.13                 | -2.9  | -0.13 | -2.9  | -0.09 | -1.9  | -0.15 | -3.1  | -0.14 | -2.7  | -0.3  | -5.4  | -0.21 | -3.6  | -0.18 | -3.0  | -0.08 | -1.3  |
| MR2  | 0.21                  | 5.2   | 0.24  | 5.8   | 0.18  | 4.2   | 0.11  | 2.4   | -0.05 | -1.0  | -0.2  | -3.6  | -0.17 | -2.9  | -0.1  | -1.7  | -0.13 | -2.2  |
| MR3  | 0.52                  | 14.1  | 0.5   | 12.9  | 0.47  | 11.8  | 0.49  | 11.7  | 0.43  | 9.5   | 0.15  | 3.0   | -0.22 | -3.9  | -0.25 | -4.2  | -0.3  | -4.8  |
| MR4  | 0.5                   | 12.9  | 0.43  | 10.7  | 0.48  | 11.7  | 0.39  | 8.9   | 0.44  | 9.5   | 0.41  | 8.4   | 0.51  | 10.1  | 0.5   | 9.7   | 0.56  | 10.4  |
| MR5  | 0.72                  | 48.3  | 0.78  | 37.3  | 0.7   | 29.0  | 0.79  | 25.9  | 0.38  | 7.6   | -0.04 | -0.6  | -0.05 | -0.8  | -0.11 | -1.6  | -0.07 | -1.0  |
| MR6  | 0.53                  | 25.1  | 0.16  | 6.4   | -0.35 | -11.6 | -0.81 | -23.1 | -2.8  | -49.9 | -3.34 | -52.5 | -3.54 | -52.1 | -3.67 | -52.0 | -3.83 | -52.3 |
| LBR1 | -0.44                 | -12.3 | -0.47 | -10.8 | -0.39 | -8.2  | -0.35 | -6.8  | 0.35  | 6.4   | 0.45  | 8.0   | 0.34  | 5.7   | 0.37  | 6.0   | 0.2   | 3.1   |
| LBR2 | 0.79                  | 21.4  | 0.73  | 16.9  | 0.73  | 18.4  | 0.76  | 18.3  | 0.75  | 17.1  | 0.79  | 17.2  | 0.79  | 16.8  | 0.82  | 16.8  | 1.22  | 23.2  |
| LBR3 | -0.3                  | -10.4 | -0.68 | -17.7 | -0.61 | -17.6 | -0.61 | -16.6 | -0.6  | -15.2 | -0.7  | -16.1 | -0.91 | -19.2 | -1.09 | -21.8 | -1.2  | -22.9 |
| BR1  | -1.76                 | -51.0 | -1.32 | -37.5 | -0.77 | -21.4 | -0.21 | -5.4  | 0.23  | 5.7   | 0.37  | 8.7   | 0.27  | 5.9   | 0.25  | 5.4   | 0.31  | 6.6   |
| BR2  | -1.26                 | -49.4 | -1.31 | -46.1 | -1.25 | -41.8 | -1.02 | -31.5 | -0.79 | -23.0 | -0.74 | -20.0 | -0.64 | -16.7 | -0.63 | -16.0 | -0.57 | -14.1 |
| BR3  | -1.55                 | -51.2 | -1.51 | -46.3 | -1.57 | -45.6 | -1.54 | -42.5 | -1.48 | -38.1 | -1.21 | -30.6 | -0.8  | -19.6 | -0.74 | -17.8 | -0.61 | -14.4 |
| SCH1 | -0.17                 | -4.1  | 0     | 0.0   | 0     | 0.0   | 0.04  | 1.4   | 0.2   | 6.6   | 0.62  | 18.2  | 0.56  | 14.9  | 0.56  | 14.4  | 0.47  | 11.4  |
| SCH2 | 0                     | 0.0   | -0.06 | -1.5  | -0.03 | -0.7  | -0.04 | -1.0  | -0.04 | -0.9  | -0.04 | -0.9  | -0.05 | -1.1  | -0.04 | -0.9  | -0.04 | -0.8  |
| SR   | -0.01                 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | 0     | 0.0   | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  |
| StbR | 0.11                  | 2.9   | 0.14  | 3.3   | 0.12  | 2.6   | 0.13  | 2.6   | -0.01 | -0.2  | -0.07 | -1.1  | -0.11 | -1.7  | -0.11 | -1.7  | -0.12 | -1.6  |

Table A-5 Delta (Project – Existing) D.O. Percentiles for Critical Cells: Plan 6b, 2 ft deepening, No injections

| Zone | Delta D.O. Percentile |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|------|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|      | 1%                    |       | 5%    |       | 10%   |       | 25%   |       | 50%   |       | 75%   |       | 90%   |       | 95%   |       | 99    |       |
|      | mg/l                  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     |
| FR1  | -0.02                 | -0.5  | -0.03 | -0.8  | -0.05 | -1.2  | -0.03 | -0.7  | -0.04 | -0.9  | 0     | 0.0   | -0.02 | -0.4  | -0.03 | -0.6  | -0.01 | -0.2  |
| FR2  | -0.25                 | -6.6  | 0.12  | 3.2   | 0.28  | 7.3   | 0.41  | 10.2  | 0.38  | 9.0   | 0.41  | 9.3   | 0.35  | 7.6   | 0.45  | 9.6   | 0.26  | 5.1   |
| FR3  | 0.09                  | 2.6   | 0.02  | 0.6   | 0.06  | 1.4   | 0.07  | 1.8   | 0.03  | 0.7   | 0.03  | 0.7   | 0.07  | 1.5   | 0.18  | 3.6   | 0     | 0.0   |
| FR4  | 0.07                  | 2.0   | 0.06  | 1.7   | 0.06  | 1.7   | 0.03  | 0.6   | 0.03  | 0.7   | -0.06 | -1.4  | -0.13 | -2.6  | -0.09 | -1.7  | 0.03  | 0.5   |
| FR5  | 0.08                  | 2.2   | 0     | 0.0   | 0.09  | 2.3   | 0.05  | -1.2  | -0.15 | -3.5  | -0.5  | -10.2 | -0.36 | -6.5  | -0.28 | -5.0  | -0.23 | -4.0  |
| FR6  | 0.06                  | 1.6   | 0.08  | 2.1   | 0.02  | 0.5   | 0     | 0.0   | 0     | 0.0   | -0.25 | -5.2  | -0.25 | -4.5  | -0.18 | -3.1  | -0.19 | -3.2  |
| FR7  | 0.38                  | 9.1   | 0.4   | 9.4   | 0.47  | 10.9  | 0.45  | 9.8   | 0.58  | 11.3  | 0.13  | 2.2   | 0.12  | 1.9   | 0.17  | 2.7   | 0.54  | 8.3   |
| FR8  | -0.14                 | -3.0  | -0.17 | -3.6  | -0.28 | -5.5  | -0.4  | -7.3  | -0.16 | -2.6  | -0.12 | -1.9  | -0.18 | -2.7  | -0.17 | -2.5  | -0.22 | -3.1  |
| FR9  | 0.28                  | 5.7   | 0.61  | 12.1  | 0.47  | 8.8   | 0.44  | 7.7   | 0.18  | 2.9   | 0.15  | 2.3   | 0.21  | 3.1   | 0.16  | 2.3   | 0.16  | 2.7   |
| FR10 | 0.3                   | 7.0   | 0.23  | 4.8   | 0.19  | 3.8   | 0.16  | 3.0   | -0.05 | -0.8  | -0.17 | -2.6  | -0.1  | -1.5  | -0.24 | -3.4  | -0.09 | -1.2  |
| FR11 | -1.46                 | -35.0 | -1.99 | -42.3 | -2.21 | -44.8 | -2.5  | -47.7 | -2.89 | -51.0 | -3.25 | -62.9 | -3.47 | -63.4 | -3.53 | -63.2 | -3.95 | -65.4 |
| MR1  | -0.1                  | -2.3  | -0.1  | -2.2  | -0.05 | -1.1  | -0.13 | -2.7  | -0.13 | -2.5  | -0.27 | -4.8  | -0.15 | -2.5  | -0.09 | -1.5  | -0.04 | -0.8  |
| MR2  | 0.16                  | 4.0   | 0.17  | 4.1   | 0.07  | 1.6   | 0.02  | 0.4   | -0.13 | -2.6  | -0.21 | -3.8  | -0.11 | -1.9  | -0.09 | -1.5  | -0.09 | -1.5  |
| MR3  | 0.41                  | 11.1  | 0.32  | 8.2   | 0.34  | 8.5   | 0.32  | 7.6   | 0.28  | 6.2   | 0.01  | 0.2   | -0.43 | -7.5  | -0.45 | -7.6  | -0.47 | -7.6  |
| MR4  | -0.05                 | -1.3  | 0.65  | 16.1  | 0.79  | 19.2  | 0.82  | 18.7  | 0.86  | 18.7  | 0.88  | 18.0  | 1     | 19.8  | 1.07  | 20.7  | 1.31  | 24.2  |
| MR5  | -0.09                 | -6.0  | -0.48 | -23.5 | -0.59 | -24.5 | -0.5  | -16.4 | 0.04  | 0.8   | -0.12 | -1.9  | -0.12 | -1.6  | -0.12 | -2.5  | -0.13 | -1.8  |
| MR6  | 3.32                  | 157.3 | 3.37  | 135.3 | 3.16  | 105.0 | 3.03  | 89.3  | 1.19  | 21.2  | 0.79  | 12.4  | 0.58  | 8.5   | 0.41  | 5.8   | 0.25  | 3.4   |
| LBR1 | -0.39                 | -10.9 | -0.14 | -3.2  | 0.08  | 1.7   | 0.13  | 2.5   | 0.07  | 1.3   | 0.16  | 2.8   | 0.11  | 1.8   | 0.13  | 2.1   | 0.05  | 0.8   |
| LBR2 | 0.14                  | 3.8   | 0.26  | 6.7   | 0.24  | 6.0   | 0.25  | 6.0   | 0.25  | 5.7   | 0.27  | 5.9   | 0.25  | 5.2   | 0.3   | 6.1   | 0.43  | 8.2   |
| LBR3 | -1.13                 | -39.1 | -1.32 | -40.2 | -1.4  | -40.3 | -1.29 | -35.1 | -1.21 | -30.6 | -1.25 | -28.8 | -1.43 | -30.2 | -1.56 | -31.3 | -1.71 | -32.6 |
| BR1  | -2.32                 | -67.2 | -1.76 | -50.0 | -1.04 | -29.0 | -0.37 | -9.5  | 0.17  | 4.2   | 0.36  | 8.5   | 0.27  | 5.9   | 0.26  | 5.6   | 0.32  | 6.8   |
| BR2  | -1.93                 | -57.7 | -1.85 | -68.7 | -1.83 | -61.2 | -1.41 | -43.5 | -1.06 | -30.8 | -1.02 | -27.6 | -0.87 | -22.7 | -0.82 | -20.9 | -0.75 | -18.6 |
| BR3  | -2.22                 | -73.3 | -2.19 | -67.2 | -2.21 | -64.2 | -2.14 | -59.1 | -2.03 | -53.7 | -1.57 | -39.7 | -1.08 | -26.5 | -0.97 | -23.4 | -0.87 | -20.5 |
| SCH1 | -0.06                 | -2.6  | -0.06 | -2.3  | 0     | 0.0   | 0.02  | 0.7   | 0.04  | 1.3   | -0.11 | -3.2  | -0.11 | -2.9  | -0.07 | -1.8  | -0.14 | -3.4  |
| SCH2 | 0                     | 0.0   | 0.04  | -1.0  | 0.04  | -1.0  | 0.04  | -1.0  | -0.04 | -0.9  | -0.04 | -0.9  | -0.04 | -0.9  | -0.04 | -0.9  | -0.01 | -0.2  |
| SR   | -0.01                 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | 0     | 0.0   | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  | -0.01 | -0.2  |
| StbR | 0.23                  | 6.0   | 0.26  | 6.2   | 0.17  | 3.7   | 0.18  | 3.6   | 0.02  | 0.4   | -0.06 | -1.0  | -0.07 | -1.1  | -0.07 | -1.1  | -0.06 | -0.9  |

Table A-6 Delta (Project – Existing) D.O. Percentiles for Zones' Averages: Plan 6a, 6 ft deepening, No injections

| Zone Name | Project - Baseline Difference (mg/l) |       |       |       |       |       |       |       |       | Project - Baseline Relative Difference (%) |       |       |       |       |       |       |       |       |
|-----------|--------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|--------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
|           | 1%                                   | 5%    | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   | 1%                                         | 5%    | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   |
| FR1       | -0.05                                | -0.07 | -0.07 | -0.04 | -0.07 | -0.09 | -0.13 | -0.11 | -0.13 | -1.2                                       | -1.6  | -1.7  | -0.9  | -1.5  | -1.9  | -2.6  | -2.3  | -2.5  |
| FR2       | 0.03                                 | -0.02 | -0.04 | -0.03 | -0.07 | -0.09 | -0.14 | -0.14 | -0.14 | 0.7                                        | -0.5  | -1.0  | -0.7  | -1.6  | -1.9  | -2.8  | -2.9  | -2.8  |
| FR3       | -0.08                                | -0.07 | -0.06 | -0.08 | -0.10 | -0.16 | -0.26 | -0.39 | -0.52 | -2.0                                       | -1.6  | -1.4  | -1.8  | -2.1  | -3.3  | -5.3  | -7.6  | -9.9  |
| FR4       | -0.11                                | -0.10 | -0.12 | -0.12 | -0.20 | -0.37 | -0.66 | -0.71 | -0.77 | -2.6                                       | -2.4  | -2.9  | -2.8  | -4.4  | -7.6  | -10.7 | -12.6 | -13.1 |
| FR5       | -0.11                                | -0.15 | -0.15 | -0.19 | -0.30 | -0.52 | -0.75 | -0.71 | -0.63 | -2.7                                       | -3.5  | -3.5  | -4.2  | -6.3  | -10.0 | -13.2 | -12.0 | -10.4 |
| FR6       | -0.15                                | -0.19 | -0.27 | -0.32 | -0.52 | -0.74 | -0.82 | -0.57 | -0.48 | -3.6                                       | -4.4  | -6.0  | -6.9  | -10.3 | -13.2 | -13.8 | -9.4  | -7.8  |
| FR7       | -0.28                                | -0.36 | -0.42 | -0.53 | -0.69 | -0.45 | -0.38 | 0.37  | -0.38 | -6.0                                       | -7.4  | -8.4  | -10.0 | -11.5 | -7.1  | -5.8  | -5.5  | -5.5  |
| FR8       | -0.40                                | -0.54 | -0.54 | -0.60 | -0.49 | -0.29 | -0.26 | -0.35 | -0.33 | -7.8                                       | -10.0 | -9.8  | -10.2 | -7.7  | -4.3  | -3.8  | -4.9  | -4.6  |
| FR9       | -0.56                                | -0.50 | -0.50 | -0.37 | -0.23 | -0.19 | -0.23 | -0.19 | -0.16 | -9.7                                       | -8.3  | -8.1  | -5.6  | -3.5  | -2.7  | -3.1  | -2.6  | -2.2  |
| FR10      | -0.21                                | -0.08 | -0.10 | -0.12 | -0.10 | -0.08 | -0.07 | -0.07 | -0.08 | -3.6                                       | -1.6  | -1.6  | -1.8  | -1.5  | -1.2  | -0.9  | -1.0  | -1.0  |
| FR11      | -0.42                                | -0.40 | -0.41 | -0.44 | -0.47 | -0.46 | -0.52 | -0.51 | -0.48 | -7.3                                       | -6.8  | -6.9  | -7.0  | -7.1  | -6.7  | -7.1  | -7.1  | -6.5  |
| MR1       | -0.27                                | -0.28 | -0.28 | -0.30 | -0.33 | -0.45 | -0.40 | -0.39 | -0.34 | -5.6                                       | -5.8  | -5.6  | -5.7  | -6.0  | -7.6  | -8.7  | -8.3  | -5.5  |
| MR2       | -0.02                                | -0.04 | -0.09 | -0.15 | -0.24 | -0.40 | -0.40 | -0.39 | -0.27 | -0.4                                       | -0.8  | -1.7  | -2.8  | -4.3  | -6.8  | -6.5  | -6.4  | -4.3  |
| MR3       | 0.24                                 | 0.16  | 0.14  | 0.12  | 0.05  | -0.14 | -0.31 | -0.31 | -0.36 | 5.3                                        | 3.4   | 3.0   | 2.4   | 1.0   | -2.5  | -5.1  | -5.0  | -5.7  |
| MR4       | 0.13                                 | 0.06  | 0.13  | 0.18  | 0.16  | 0.17  | 0.21  | 0.29  | 0.30  | 2.6                                        | 1.2   | 2.5   | 3.2   | 2.8   | 2.9   | 3.5   | 4.7   | 4.8   |
| MR5       | 0.04                                 | 0.14  | 0.15  | 0.14  | 0.03  | -0.05 | -0.07 | -0.15 | -0.07 | 1.1                                        | 3.1   | 3.2   | 2.8   | 0.6   | -0.7  | -1.0  | -2.2  | -0.9  |
| MR6       | -0.16                                | -0.25 | -0.34 | -0.44 | -0.89 | -1.16 | -1.41 | -1.48 | -1.64 | -3.8                                       | -5.6  | -7.1  | -8.6  | -15.1 | -17.9 | -20.2 | -20.8 | -22.3 |
| LBR1      | 0.14                                 | 0.16  | 0.22  | 0.21  | 0.25  | 0.30  | 0.35  | 0.41  | 0.41  | 3.0                                        | 3.3   | 4.2   | 4.0   | 4.5   | 5.3   | 5.9   | 6.9   | 6.8   |
| LBR2      | 0.33                                 | 0.29  | 0.28  | 0.35  | 0.36  | 0.37  | 0.46  | 0.45  | 0.43  | 7.5                                        | 6.4   | 6.1   | 7.2   | 7.0   | 7.0   | 8.6   | 8.3   | 7.8   |
| LBR3      | -0.28                                | -0.18 | -0.14 | -0.13 | -0.09 | 0.01  | 0.10  | 0.14  | 0.23  | -6.7                                       | -4.4  | -3.3  | -2.9  | -2.0  | 0.3   | 2.1   | 2.8   | 4.6   |
| BR1       | -0.86                                | -0.46 | -0.28 | -0.07 | 0.12  | 0.12  | 0.11  | 0.08  | 0.09  | -23.1                                      | -12.0 | -7.0  | -1.7  | 2.7   | 2.7   | 2.4   | 1.7   | 1.9   |
| BR2       | -1.08                                | -1.04 | -1.01 | -0.84 | -0.63 | -0.13 | -0.05 | -0.18 | -0.32 | -29.9                                      | -28.3 | -27.0 | -24.5 | -15.7 | -3.0  | -1.1  | -4.0  | -2.6  |
| BR3       | -1.07                                | -1.02 | -1.00 | -0.84 | -0.94 | -0.86 | -0.72 | -0.62 | -0.63 | -28.1                                      | -26.8 | -26.1 | -24.0 | -23.2 | -20.5 | -16.8 | -14.3 | -14.2 |
| SCH1      | -0.22                                | -0.20 | -0.19 | -0.14 | -0.14 | -0.18 | -0.21 | -0.21 | -0.21 | -5.2                                       | -4.7  | -4.5  | -3.3  | -3.2  | -4.1  | -4.5  | -4.4  | -4.3  |
| SCH2      | -0.17                                | -0.13 | -0.16 | -0.13 | -0.13 | -0.17 | -0.19 | -0.17 | -0.23 | -3.9                                       | -3.0  | -3.5  | -2.9  | -2.7  | -3.4  | -3.8  | -3.4  | -4.5  |
| SR        | -0.15                                | -0.15 | -0.15 | -0.16 | -0.15 | -0.13 | -0.18 | -0.17 | -0.18 | -2.5                                       | -2.6  | -2.4  | -2.4  | -2.1  | -1.9  | -2.4  | -2.3  | -2.3  |
| StbR      | -0.21                                | -0.14 | -0.18 | -0.22 | -0.22 | -0.25 | -0.28 | -0.35 | -0.43 | -3.9                                       | -2.6  | -3.3  | -3.9  | -3.6  | -4.0  | -4.3  | -5.3  | -6.4  |

Table A-7 Delta (Project – Existing) D.O. Percentiles for Zones' Averages: Plan 6a, 5 ft deepening, No injections

| Zone Name | Project - Baseline Difference (mg/l) |       |       |       |       |       |       |       |       | Project - Baseline Relative Difference (%) |       |       |       |       |       |       |       |       |
|-----------|--------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|--------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
|           | 1%                                   | 5%    | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   | 1%                                         | 5%    | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   |
| FR1       | -0.06                                | -0.09 | -0.07 | -0.05 | -0.08 | -0.10 | -0.12 | -0.10 | -0.12 | -1.4                                       | -2.0  | -1.6  | -1.2  | -1.7  | -2.0  | -2.5  | -2.1  | -2.5  |
| FR2       | 0.02                                 | -0.03 | -0.04 | -0.03 | -0.08 | -0.08 | -0.12 | -0.14 | -0.14 | 0.5                                        | -0.7  | -0.9  | -0.7  | -1.7  | -1.6  | -2.5  | -2.8  | -2.8  |
| FR3       | -0.08                                | -0.07 | -0.06 | -0.09 | -0.10 | -0.15 | -0.23 | -0.36 | -0.49 | -2.1                                       | -1.8  | -1.6  | -2.1  | -2.2  | -3.3  | -4.7  | -7.1  | -9.3  |
| FR4       | -0.11                                | -0.10 | -0.12 | -0.12 | -0.20 | -0.35 | -0.50 | -0.83 | -0.83 | -2.8                                       | -2.5  | -2.9  | -2.8  | -4.4  | -7.2  | -9.5  | -11.2 | -10.7 |
| FR5       | -0.11                                | -0.15 | -0.15 | -0.18 | -0.28 | -0.48 | -0.64 | -0.87 | -0.50 | -2.6                                       | -3.5  | -3.3  | -4.0  | -6.0  | -8.3  | -11.3 | -9.7  | -8.3  |
| FR6       | -0.14                                | -0.19 | -0.27 | -0.30 | -0.49 | -0.66 | -0.67 | -0.46 | -0.37 | -3.4                                       | -4.3  | -5.9  | -6.5  | -9.6  | -11.9 | -11.2 | -7.5  | -5.9  |
| FR7       | -0.26                                | -0.33 | -0.38 | -0.48 | -0.61 | -0.37 | -0.33 | -0.34 | -0.38 | -5.6                                       | -6.8  | -7.7  | -9.1  | -10.2 | -5.9  | -5.1  | -5.1  | -5.5  |
| FR8       | -0.36                                | -0.49 | -0.51 | -0.56 | -0.38 | -0.26 | -0.24 | -0.32 | -0.25 | -7.0                                       | -9.1  | -9.2  | -9.5  | -6.0  | -3.8  | -3.5  | -4.5  | -3.4  |
| FR9       | -0.49                                | -0.42 | -0.42 | -0.31 | -0.20 | -0.17 | -0.20 | -0.16 | -0.13 | -8.5                                       | -7.0  | 6.9   | 4.8   | -3.0  | -2.5  | 2.8   | 2.1   | -1.7  |
| FR10      | -0.22                                | -0.09 | -0.10 | -0.12 | -0.10 | -0.08 | -0.05 | -0.06 | -0.07 | -3.6                                       | -1.6  | -1.8  | -1.8  | -1.5  | -1.2  | -0.7  | -0.8  | -1.0  |
| FR11      | 0.42                                 | 0.40  | 0.41  | 0.45  | 0.47  | 0.46  | 0.52  | 0.51  | 0.48  | 7.3                                        | 6.8   | 6.8   | 7.0   | 7.1   | 6.7   | 7.1   | 7.1   | 6.5   |
| MR1       | -0.26                                | -0.28 | -0.26 | -0.27 | -0.30 | -0.41 | -0.36 | -0.31 | -0.35 | -5.3                                       | -5.4  | -5.2  | -5.2  | -6.3  | -7.0  | -5.9  | -5.1  | -5.5  |
| MR2       | 0.00                                 | -0.03 | -0.08 | -0.12 | -0.22 | -0.35 | -0.33 | -0.32 | -0.25 | 0.0                                        | -0.6  | -1.6  | -2.3  | -3.9  | -5.9  | -5.5  | -5.2  | -4.1  |
| MR3       | 0.23                                 | 0.16  | 0.17  | 0.14  | 0.06  | -0.14 | -0.29 | -0.29 | -0.35 | 5.1                                        | 3.4   | 3.5   | 2.8   | 1.2   | -2.3  | -4.7  | -4.7  | -5.5  |
| MR4       | 0.14                                 | 0.05  | 0.13  | 0.17  | 0.15  | 0.17  | 0.21  | 0.29  | 0.30  | 2.7                                        | 1.0   | 2.5   | 3.1   | 2.7   | 2.9   | 3.5   | 4.7   | 4.9   |
| MR5       | 0.05                                 | 0.13  | 0.15  | 0.15  | 0.03  | -0.05 | -0.07 | -0.15 | -0.07 | 1.2                                        | 2.9   | 3.1   | 2.9   | 0.6   | -0.7  | -1.0  | -2.1  | -0.9  |
| MR6       | -0.15                                | -0.24 | -0.34 | -0.45 | -0.30 | -1.16 | -1.40 | -1.49 | -1.64 | -3.6                                       | -5.4  | -7.2  | -8.8  | -15.1 | -17.9 | -20.2 | -20.8 | -22.3 |
| LBR1      | 0.14                                 | 0.17  | 0.22  | 0.21  | 0.24  | 0.29  | 0.35  | 0.41  | 0.40  | 2.8                                        | 3.4   | 4.4   | 4.0   | 4.4   | 5.1   | 6.0   | 6.9   | 6.7   |
| LBR2      | 0.33                                 | 0.30  | 0.29  | 0.34  | 0.35  | 0.38  | 0.45  | 0.43  | 0.45  | 7.4                                        | 6.5   | 6.3   | 7.0   | 6.6   | 7.2   | 8.5   | 8.0   | 8.2   |
| LBR3      | -0.26                                | -0.17 | -0.13 | -0.12 | -0.09 | 0.02  | 0.11  | 0.13  | 0.23  | -6.2                                       | -4.0  | -2.9  | -2.7  | -2.0  | 0.5   | 2.1   | 2.5   | 4.5   |
| BR1       | -0.93                                | -0.52 | -0.33 | -0.11 | 0.09  | 0.12  | 0.11  | 0.09  | 0.11  | -24.9                                      | -13.7 | -8.3  | -2.7  | 2.1   | 2.7   | 2.4   | 2.0   | 2.2   |
| BR2       | -1.15                                | -1.09 | -1.06 | -1.01 | -0.89 | -0.17 | -0.08 | -0.18 | -0.15 | -31.8                                      | -29.7 | -28.3 | -26.2 | -17.3 | -4.0  | -1.7  | -4.0  | -3.2  |
| BR3       | -1.13                                | -1.07 | -1.04 | -0.97 | -0.95 | -0.87 | -0.71 | -0.61 | -0.62 | -29.7                                      | -28.0 | -27.1 | -24.8 | -23.5 | -20.8 | -18.6 | -14.0 | -14.0 |
| SCh1      | -0.22                                | -0.20 | -0.19 | -0.14 | -0.15 | -0.18 | -0.20 | -0.18 | -0.17 | -6.2                                       | -4.8  | -4.5  | -3.4  | -3.3  | -3.9  | -4.2  | -3.9  | -3.6  |
| SCh2      | -0.17                                | -0.12 | -0.15 | -0.13 | -0.13 | -0.16 | -0.19 | -0.16 | -0.20 | -3.9                                       | -2.8  | -3.3  | -2.8  | -2.7  | -3.3  | -3.7  | -3.2  | -3.8  |
| SR        | -0.15                                | -0.15 | -0.15 | -0.16 | -0.15 | -0.13 | -0.18 | -0.17 | -0.18 | -2.5                                       | -2.6  | -2.4  | -2.4  | -2.1  | -1.9  | -2.4  | -2.3  | -2.3  |
| StdR      | -0.17                                | -0.11 | -0.17 | -0.20 | -0.19 | -0.22 | -0.24 | -0.31 | -0.35 | -3.2                                       | -2.1  | -3.1  | -3.4  | -3.1  | -3.5  | -3.8  | -4.7  | -5.1  |

Table A-8 Delta (Project – Existing) D.O. Percentiles for Zones' Averages: Plan 6a, 4 ft deepening, No injections

| Zone Name | Project - Baseline Difference (mg/l) |       |       |       |       |       |       |       |       | Project - Baseline Relative Difference (%) |       |       |       |       |       |       |       |       |
|-----------|--------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|--------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
|           | 1%                                   | 5%    | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   | 1%                                         | 5%    | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   |
| FR1       | -0.06                                | -0.08 | -0.09 | -0.06 | -0.06 | -0.09 | -0.12 | -0.12 | -0.15 | -1.5                                       | -1.9  | -1.9  | -1.2  | -1.3  | -1.9  | -2.5  | -2.4  | -2.9  |
| FR2       | 0.02                                 | -0.03 | -0.05 | -0.02 | -0.07 | -0.06 | -0.10 | -0.11 | -0.12 | 0.4                                        | -0.7  | -1.2  | -0.5  | -1.4  | -1.3  | -2.1  | -2.2  | -2.4  |
| FR3       | -0.12                                | -0.07 | -0.06 | -0.07 | -0.09 | -0.14 | -0.18 | -0.30 | -0.43 | -2.9                                       | -1.8  | -1.5  | -1.6  | -2.0  | -3.0  | -3.8  | -5.9  | -8.1  |
| FR4       | -0.12                                | -0.11 | -0.13 | -0.12 | -0.19 | -0.32 | -0.44 | -0.52 | -0.51 | -3.0                                       | -2.8  | -3.0  | -2.6  | -4.0  | -6.6  | -8.3  | -9.2  | -8.7  |
| FR5       | -0.12                                | -0.15 | -0.14 | -0.17 | -0.26 | -0.43 | -0.56 | -0.45 | -0.41 | -2.8                                       | -3.3  | -3.2  | -3.7  | -5.6  | -8.3  | -9.9  | -7.5  | -6.8  |
| FR6       | -0.13                                | -0.17 | -0.25 | -0.28 | -0.45 | -0.59 | -0.55 | -0.35 | -0.29 | -3.2                                       | -4.0  | -5.4  | -6.0  | -8.8  | -10.5 | -9.0  | -5.7  | -4.7  |
| FR7       | -0.23                                | -0.28 | -0.34 | -0.44 | -0.49 | -0.29 | -0.28 | -0.31 | -0.33 | -5.1                                       | -5.9  | -6.9  | -8.2  | -8.2  | -4.6  | -4.3  | -4.6  | -4.8  |
| FR8       | -0.34                                | -0.43 | -0.46 | -0.51 | -0.30 | -0.22 | -0.20 | -0.29 | -0.27 | -6.6                                       | -8.0  | -8.3  | -8.6  | -4.8  | -3.3  | -2.9  | -4.1  | -3.8  |
| FR9       | -0.42                                | -0.35 | -0.34 | -0.27 | -0.15 | -0.14 | -0.18 | -0.12 | -0.11 | -7.2                                       | -5.8  | -5.6  | -4.3  | -2.3  | -2.1  | -2.4  | -1.6  | -1.5  |
| FR10      | -0.22                                | -0.10 | -0.10 | -0.12 | -0.10 | -0.08 | -0.05 | -0.05 | -0.07 | -3.7                                       | -1.6  | -1.6  | -1.8  | -1.5  | -1.2  | -0.7  | -0.7  | -0.9  |
| FR11      | -0.42                                | -0.40 | -0.41 | -0.45 | -0.47 | -0.46 | -0.52 | -0.51 | -0.48 | -7.3                                       | -6.8  | -6.9  | -7.0  | -7.1  | -6.7  | -7.2  | -7.0  | -6.5  |
| MR1       | -0.23                                | -0.23 | -0.24 | -0.24 | -0.27 | -0.37 | -0.31 | -0.28 | -0.29 | -4.9                                       | -4.7  | -4.8  | -4.7  | -4.8  | -6.2  | -5.1  | -4.6  | -4.6  |
| MR2       | 0.01                                 | 0.00  | -0.06 | -0.09 | -0.17 | -0.31 | -0.29 | -0.30 | -0.24 | 0.2                                        | 0.0   | -1.3  | -1.7  | -3.1  | -5.2  | -4.7  | -4.8  | -3.9  |
| MR3       | 0.25                                 | 0.17  | 0.17  | 0.14  | 0.08  | -0.12 | -0.27 | -0.29 | -0.33 | 5.4                                        | 3.7   | 3.5   | 2.7   | 1.5   | -2.1  | -4.4  | -4.7  | -5.3  |
| MR4       | 0.14                                 | 0.05  | 0.12  | 0.17  | 0.16  | 0.17  | 0.22  | 0.28  | 0.29  | 2.8                                        | 1.0   | 2.3   | 3.1   | 2.8   | 2.9   | 3.6   | 4.6   | 4.7   |
| MR5       | 0.05                                 | 0.12  | 0.15  | 0.14  | 0.04  | -0.05 | -0.08 | -0.15 | -0.07 | 1.2                                        | 2.7   | 3.3   | 2.8   | 0.6   | -0.8  | -1.1  | -2.1  | -0.9  |
| MR6       | -0.14                                | -0.24 | -0.34 | -0.43 | -0.30 | -1.16 | -1.40 | -1.49 | -1.64 | -3.4                                       | -5.3  | -7.2  | -8.4  | -15.1 | -17.9 | -20.2 | -20.8 | -22.3 |
| LBR1      | 0.13                                 | 0.17  | 0.22  | 0.21  | 0.24  | 0.30  | 0.36  | 0.41  | 0.40  | 2.7                                        | 3.3   | 4.3   | 4.0   | 4.4   | 5.2   | 6.2   | 6.9   | 6.6   |
| LBR2      | 0.33                                 | 0.29  | 0.29  | 0.34  | 0.36  | 0.37  | 0.46  | 0.44  | 0.47  | 7.4                                        | 6.4   | 6.2   | 7.1   | 7.0   | 7.1   | 8.6   | 8.2   | 8.6   |
| LBR3      | -0.24                                | -0.16 | -0.12 | -0.12 | -0.09 | 0.02  | 0.11  | 0.13  | 0.24  | -5.9                                       | -3.9  | -2.8  | -2.6  | -1.9  | 0.5   | 2.1   | 2.6   | 4.7   |
| BR1       | -0.98                                | -0.59 | -0.38 | -0.13 | 0.09  | 0.13  | 0.13  | 0.10  | 0.11  | -26.4                                      | -15.6 | -9.5  | -3.1  | 2.1   | 3.0   | 2.7   | 2.1   | 2.4   |
| BR2       | -1.23                                | -1.16 | -1.10 | -1.06 | -0.76 | -0.19 | -0.10 | -0.23 | -0.16 | -34.0                                      | -31.4 | -29.4 | -27.6 | -19.0 | -4.5  | -2.2  | -4.9  | -3.4  |
| BR3       | -1.15                                | -1.11 | -1.06 | -0.98 | -0.95 | -0.87 | -0.70 | -0.60 | -0.60 | -30.3                                      | -29.1 | -27.8 | -25.1 | -23.4 | -20.8 | -16.2 | -13.8 | -13.5 |
| SCh1      | -0.20                                | -0.18 | -0.17 | -0.13 | -0.13 | -0.17 | -0.19 | -0.21 | -0.20 | -4.9                                       | -4.3  | -4.0  | -3.1  | -3.1  | -3.8  | -4.2  | -4.5  | -4.2  |
| SCh2      | -0.17                                | -0.13 | -0.15 | -0.13 | -0.11 | -0.14 | -0.16 | -0.14 | -0.18 | -4.0                                       | -3.0  | -3.3  | -2.8  | -2.3  | -2.8  | -3.2  | -2.8  | -3.5  |
| SR        | -0.15                                | -0.15 | -0.15 | -0.16 | -0.15 | -0.13 | -0.18 | -0.17 | -0.18 | -2.5                                       | -2.6  | -2.4  | -2.4  | -2.1  | -1.9  | -2.4  | -2.3  | -2.3  |
| StdR      | -0.13                                | -0.08 | -0.14 | -0.16 | -0.15 | -0.17 | -0.21 | -0.28 | -0.31 | -2.4                                       | -1.5  | -2.6  | -2.8  | -2.5  | -2.8  | -3.2  | -4.2  | -4.6  |



Table A-9 Delta (Project – Existing) D.O. Percentiles for Zones' Averages: Plan 6a, 3 ft deepening, No injections

| Zone Name | Project - Baseline Difference (mg/l) |       |       |       |       |       |       |       |       | Project - Baseline Relative Difference (%) |       |       |       |       |       |       |       |       |
|-----------|--------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|--------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
|           | 1%                                   | 5%    | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   | 1%                                         | 5%    | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   |
| FR1       | -0.05                                | -0.08 | -0.07 | -0.05 | -0.06 | -0.08 | -0.11 | -0.11 | -0.14 | -1.2                                       | -1.7  | -1.5  | -1.0  | -1.3  | -1.7  | -2.2  | -2.3  | -2.7  |
| FR2       | 0.02                                 | -0.02 | -0.03 | -0.01 | -0.06 | -0.05 | -0.08 | -0.09 | -0.09 | 0.5                                        | -0.5  | -0.8  | -0.3  | -1.3  | -1.0  | -1.7  | -1.8  | -1.8  |
| FR3       | -0.11                                | -0.07 | -0.06 | -0.05 | -0.07 | -0.12 | -0.13 | -0.23 | -0.32 | -2.7                                       | -1.8  | -1.4  | -1.1  | -1.5  | -2.5  | -2.6  | -4.6  | -6.0  |
| FR4       | -0.12                                | -0.11 | -0.11 | -0.09 | -0.16 | -0.28 | -0.34 | -0.36 | -0.37 | -3.0                                       | -2.7  | -2.6  | -2.1  | -3.5  | -5.8  | -6.5  | -6.5  | -6.3  |
| FR5       | -0.10                                | -0.14 | -0.13 | -0.14 | -0.23 | -0.36 | -0.44 | -0.31 | -0.30 | -2.5                                       | -3.2  | -3.0  | -3.1  | -4.9  | -6.9  | -7.7  | -5.2  | -5.0  |
| FR6       | -0.13                                | -0.16 | -0.21 | -0.24 | -0.39 | -0.48 | -0.38 | -0.24 | -0.20 | -3.1                                       | -3.6  | -4.7  | -5.2  | -7.7  | -8.5  | -6.3  | -4.0  | -3.2  |
| FR7       | -0.20                                | -0.26 | -0.30 | -0.37 | -0.39 | -0.21 | -0.23 | -0.25 | -0.28 | -4.3                                       | -5.3  | -5.9  | -6.9  | -6.5  | -3.3  | -3.4  | -3.8  | -4.1  |
| FR8       | -0.30                                | -0.36 | -0.38 | -0.42 | -0.29 | -0.18 | -0.17 | -0.28 | -0.19 | -5.9                                       | -6.6  | -6.9  | -7.1  | -3.6  | -2.8  | -2.5  | -3.9  | -2.6  |
| FR9       | -0.34                                | -0.28 | -0.26 | -0.20 | -0.12 | -0.12 | -0.13 | -0.09 | -0.09 | -5.8                                       | -4.6  | -4.3  | -3.2  | -1.9  | -1.7  | -1.7  | -1.3  | -1.2  |
| FR10      | -0.22                                | -0.09 | -0.10 | -0.11 | -0.10 | -0.08 | -0.05 | -0.05 | -0.07 | -3.6                                       | -1.6  | -1.6  | -1.8  | -1.5  | -1.2  | -0.7  | -0.7  | -0.9  |
| FR11      | -0.42                                | -0.40 | -0.41 | -0.44 | -0.47 | -0.46 | -0.52 | -0.52 | -0.48 | -7.3                                       | -6.8  | -6.9  | -7.0  | -7.1  | -6.7  | -7.2  | -7.1  | -6.5  |
| MR1       | -0.21                                | -0.20 | -0.22 | -0.19 | -0.22 | -0.28 | -0.24 | -0.22 | -0.25 | -4.4                                       | -4.0  | -4.4  | -3.8  | -4.0  | -4.8  | -4.0  | -3.7  | -3.9  |
| MR2       | 0.05                                 | 0.04  | 0.04  | -0.05 | -0.13 | -0.26 | -0.23 | -0.24 | -0.23 | 1.1                                        | 0.8   | -0.8  | -1.0  | -2.3  | -4.4  | -3.9  | -3.9  | -3.7  |
| MR3       | 0.26                                 | -0.19 | 0.19  | 0.15  | 0.08  | -0.09 | -0.26 | -0.28 | -0.31 | 5.6                                        | -4.0  | -3.9  | -2.9  | 1.5   | -1.6  | -4.3  | -4.5  | -4.9  |
| MR4       | 0.13                                 | 0.06  | 0.12  | 0.16  | 0.16  | 0.17  | 0.21  | 0.28  | 0.29  | 2.8                                        | 1.2   | 2.2   | 3.0   | 2.8   | 2.8   | 3.4   | 4.6   | 4.6   |
| MR5       | -0.05                                | 0.11  | -0.16 | 0.13  | 0.04  | -0.05 | -0.08 | -0.15 | -0.07 | 1.2                                        | 2.5   | 3.1   | 2.6   | 0.6   | -0.8  | -1.2  | -2.1  | -0.9  |
| MR6       | -0.13                                | -0.23 | -0.34 | -0.45 | -0.50 | -1.16 | -1.40 | -1.49 | -1.64 | -3.1                                       | -5.1  | -7.2  | -8.8  | -15.2 | -17.9 | -20.1 | -20.8 | -22.3 |
| LBR1      | 0.13                                 | 0.17  | 0.22  | 0.21  | 0.24  | 0.28  | 0.34  | 0.41  | 0.41  | 2.6                                        | 3.4   | 4.3   | 4.0   | 4.3   | 4.8   | 5.9   | 6.6   | 6.8   |
| LBR2      | 0.33                                 | 0.30  | 0.29  | 0.34  | 0.34  | 0.38  | 0.46  | 0.43  | 0.44  | 7.8                                        | 6.5   | 6.2   | 7.0   | 8.6   | 7.3   | 8.7   | 8.0   | 8.0   |
| LBR3      | -0.23                                | -0.15 | -0.11 | -0.11 | -0.08 | 0.02  | 0.10  | 0.13  | 0.24  | -5.5                                       | -3.6  | -2.5  | -2.5  | -1.8  | 0.5   | 2.1   | 2.6   | 4.9   |
| BR1       | -1.04                                | -0.64 | -0.42 | -0.14 | 0.08  | 0.13  | 0.13  | 0.11  | 0.13  | -27.8                                      | -16.9 | -10.7 | -3.5  | 1.9   | 2.3   | 2.8   | 2.3   | 2.6   |
| BR2       | -1.31                                | -1.21 | -1.17 | -1.10 | -0.82 | -0.23 | -0.12 | -0.24 | -0.16 | -36.2                                      | -32.9 | -31.3 | -28.8 | -20.4 | -5.5  | -2.7  | -5.2  | -3.3  |
| BR3       | -1.19                                | -1.14 | -1.10 | -1.00 | -0.86 | -0.87 | -0.69 | -0.60 | -0.59 | -31.4                                      | -29.8 | -29.6 | -25.6 | -23.8 | -20.7 | -16.0 | -13.7 | -13.3 |
| Sch1      | -0.21                                | -0.19 | -0.17 | -0.13 | -0.14 | -0.18 | -0.19 | -0.20 | -0.19 | -5.0                                       | -4.5  | -3.9  | -3.1  | -2.2  | -3.9  | -4.2  | -4.2  | -3.9  |
| Sch2      | -0.16                                | -0.12 | -0.15 | -0.12 | -0.10 | -0.14 | -0.15 | -0.13 | -0.16 | -3.6                                       | -2.8  | -3.2  | -2.5  | -2.1  | -2.8  | -3.1  | -2.6  | -3.4  |
| SR        | -0.15                                | -0.15 | -0.15 | -0.16 | -0.15 | -0.13 | -0.18 | -0.17 | -0.18 | -2.5                                       | -2.6  | -2.4  | -2.4  | -2.1  | -1.9  | -2.4  | -2.3  | -2.3  |
| StbR      | -0.09                                | -0.05 | -0.11 | -0.12 | -0.11 | -0.13 | -0.15 | -0.24 | -0.25 | -1.8                                       | -0.9  | -2.0  | -2.2  | -1.9  | -2.0  | -2.4  | -3.6  | -3.7  |

Table A-10 Delta (Project – Existing) D.O. Percentiles for Zones' Averages: Plan 6b, 2 ft deepening, No injections

| Zone Name | Project - Baseline Difference (mg/l) |       |       |       |       |       |       |       |       | Project - Baseline Relative Difference (%) |       |       |       |       |       |       |       |       |
|-----------|--------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|--------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
|           | 1%                                   | 5%    | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   | 1%                                         | 5%    | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   |
| FR1       | -0.07                                | -0.09 | -0.09 | -0.08 | -0.06 | -0.08 | -0.11 | -0.10 | -0.13 | -1.6                                       | -2.1  | -1.9  | -1.6  | -1.4  | -1.6  | -2.2  | -2.1  | -2.5  |
| FR2       | 0.00                                 | -0.04 | -0.06 | -0.04 | -0.06 | -0.04 | -0.07 | -0.07 | -0.08 | 0.1                                        | -0.9  | -1.3  | -0.8  | -1.2  | -0.9  | -1.5  | -1.5  | -1.5  |
| FR3       | -0.13                                | -0.08 | -0.07 | -0.05 | -0.08 | -0.11 | -0.10 | -0.20 | -0.23 | -3.1                                       | -2.1  | -1.6  | -1.2  | -1.7  | -2.3  | -2.0  | -3.5  | -4.4  |
| FR4       | -0.13                                | -0.12 | -0.12 | -0.11 | -0.16 | -0.25 | -0.27 | -0.26 | -0.26 | -3.1                                       | -2.9  | -2.8  | -2.5  | -3.5  | -5.2  | -5.1  | -4.6  | -4.4  |
| FR5       | -0.11                                | -0.15 | -0.14 | -0.14 | -0.21 | -0.30 | -0.32 | -0.21 | -0.21 | -2.6                                       | -3.4  | -3.2  | -3.1  | -4.5  | -5.8  | -5.6  | -3.6  | -3.4  |
| FR6       | -0.12                                | -0.16 | -0.20 | -0.23 | -0.35 | -0.39 | -0.26 | -0.18 | -0.14 | -2.9                                       | -3.6  | -4.4  | -4.8  | -7.0  | -6.9  | -4.3  | -2.9  | -2.2  |
| FR7       | -0.16                                | -0.21 | -0.26 | -0.30 | -0.28 | -0.15 | -0.19 | -0.23 | -0.27 | -3.4                                       | -4.4  | -5.3  | -5.7  | -4.6  | -2.3  | -2.8  | -3.4  | -3.9  |
| FR8       | -0.22                                | -0.31 | -0.31 | -0.33 | -0.16 | -0.14 | -0.15 | -0.21 | -0.16 | -4.3                                       | -5.7  | -5.6  | -5.7  | -2.5  | -2.1  | -2.2  | -2.9  | -2.2  |
| FR9       | -0.26                                | -0.19 | -0.17 | -0.14 | -0.09 | -0.09 | -0.09 | -0.08 | -0.06 | -4.5                                       | -3.1  | -2.8  | -2.2  | -1.3  | -1.3  | -1.2  | -1.1  | -0.8  |
| FR10      | -0.22                                | -0.10 | -0.12 | -0.12 | -0.10 | -0.10 | -0.06 | -0.05 | -0.06 | -3.7                                       | -1.6  | -2.0  | -1.8  | -1.5  | -1.4  | -0.8  | -0.7  | -0.8  |
| FR11      | -0.44                                | -0.42 | -0.43 | -0.46 | -0.48 | -0.47 | -0.53 | -0.53 | -0.50 | -7.7                                       | -7.1  | -7.2  | -7.2  | -7.3  | -6.9  | -7.3  | -7.2  | -6.7  |
| MR1       | -0.18                                | -0.17 | -0.19 | -0.17 | -0.24 | -0.25 | -0.21 | -0.19 | -0.22 | -3.7                                       | -3.5  | -3.8  | -3.3  | -4.3  | -4.3  | -3.5  | -3.1  | -3.5  |
| MR2       | 0.00                                 | 0.01  | -0.08 | -0.11 | -0.14 | -0.26 | -0.22 | -0.21 | -0.19 | 0.0                                        | 0.2   | -1.6  | -2.1  | -2.3  | -4.5  | -3.7  | -3.4  | -3.1  |
| MR3       | 0.13                                 | 0.09  | 0.09  | 0.02  | -0.01 | -0.18 | -0.29 | -0.31 | -0.34 | 2.9                                        | 2.0   | 1.8   | 0.3   | -0.2  | -3.2  | -4.7  | -5.0  | -5.3  |
| MR4       | -0.03                                | -0.10 | -0.04 | -0.01 | -0.04 | -0.03 | 0.00  | 0.07  | 0.09  | -0.5                                       | -1.9  | -0.7  | -0.3  | -0.7  | -0.4  | 0.0   | 1.2   | 1.5   |
| MR5       | -0.73                                | -0.69 | -0.58 | -0.52 | -0.10 | -0.10 | -0.15 | -0.18 | -0.10 | -17.3                                      | -15.4 | -12.5 | -10.4 | -1.7  | -1.6  | -2.2  | -2.6  | -1.4  |
| MR6       | 1.62                                 | 1.49  | 1.42  | 1.31  | 0.66  | 0.38  | 0.12  | 0.01  | -0.18 | 39.0                                       | 33.1  | 29.9  | 25.8  | 11.2  | 5.8   | 1.7   | 0.1   | -2.4  |
| LBR1      | -0.09                                | -0.06 | -0.04 | -0.02 | -0.02 | 0.01  | 0.08  | 0.08  | 0.07  | -1.9                                       | -1.1  | -0.7  | -0.4  | -0.3  | 0.1   | 1.4   | 1.3   | 1.2   |
| LBR2      | 0.08                                 | 0.05  | 0.05  | 0.07  | 0.05  | 0.08  | 0.13  | 0.15  | 0.12  | 1.7                                        | 1.1   | 1.1   | 1.4   | 1.1   | 1.5   | 2.5   | 2.7   | 2.2   |
| LBR3      | 0.85                                 | 0.78  | 0.70  | 0.62  | -0.56 | -0.39 | -0.26 | -0.21 | -0.16 | -20.4                                      | -18.4 | -16.3 | -13.9 | -11.9 | -8.0  | -5.3  | -4.3  | -3.1  |
| BR1       | -1.44                                | -0.92 | -0.58 | -0.26 | 0.07  | 0.13  | 0.13  | 0.12  | 0.14  | -38.6                                      | -24.0 | -14.8 | -6.4  | 1.5   | 2.9   | 2.9   | 2.6   | 2.8   |
| BR2       | -1.98                                | -1.84 | -1.76 | -1.58 | -1.07 | -0.34 | -0.21 | -0.29 | -0.20 | -54.8                                      | -49.9 | -47.2 | -41.2 | -26.6 | -8.1  | -4.7  | -6.4  | -4.3  |
| BR3       | -1.79                                | -1.73 | -1.69 | -1.64 | -1.63 | -1.59 | -1.35 | -1.28 | -1.19 | -47.4                                      | -45.5 | -44.1 | -42.1 | -40.1 | -37.9 | -31.4 | -29.4 | -28.9 |
| Sch1      | -0.17                                | -0.18 | -0.17 | -0.15 | -0.15 | -0.16 | -0.19 | -0.20 | -0.19 | -4.2                                       | -4.2  | -3.9  | -3.4  | -3.4  | -4.0  | -4.1  | -4.3  | -4.1  |
| Sch2      | 0.16                                 | -0.12 | -0.13 | -0.13 | -0.11 | -0.13 | -0.15 | -0.13 | -0.16 | 3.5                                        | -2.7  | -2.9  | -2.6  | -2.2  | -2.7  | -3.1  | -2.6  | -3.1  |
| SR        | -0.15                                | -0.16 | -0.15 | -0.16 | -0.15 | -0.13 | -0.18 | -0.17 | -0.18 | -2.5                                       | -2.6  | -2.4  | -2.5  | -2.2  | -1.9  | -2.4  | -2.3  | -2.3  |
| StbR      | -0.05                                | -0.03 | -0.06 | -0.08 | -0.08 | -0.09 | -0.13 | -0.17 | -0.20 | -0.9                                       | -0.5  | -1.1  | -1.4  | -1.4  | -1.4  | -1.9  | -2.6  | -3.0  |



Figure A-1 Delta Bottom D.O. (50<sup>th</sup> percentile): Deepening and mitigation plan 6a-6ft



Figure A-2 Delta Bottom D.O. (50<sup>th</sup> percentile): Deepening and mitigation plan 6a-5ft

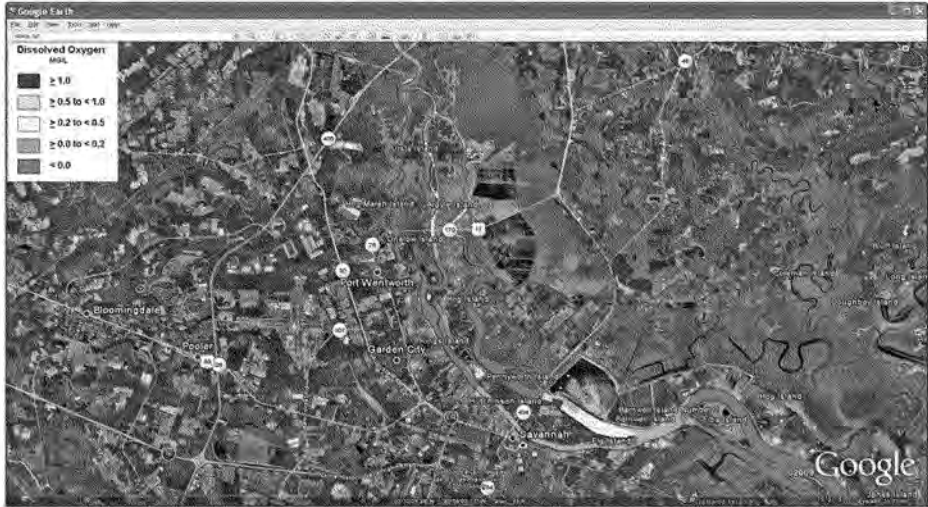


Figure A-3 Delta Bottom D.O. (50<sup>th</sup> percentile): Deepening and mitigation plan 6a-4ft



Figure A-4 Delta Bottom D.O. (50<sup>th</sup> percentile): Deepening and mitigation plan 6a-3ft



Figure A-5 Delta Bottom D.O. (50<sup>th</sup> percentile): Deepening and mitigation plan 6b-2ft

**APPENDIX B**

**DISSOLVED OXYGEN REGIME OF SAVANNAH ESTUARY:  
AUGUST 1997 (AVERAGE FLOW), ALTERNATIVE DEEPENING WITH  
MITIGATION PLANS 6A AND 6B,  
D.O. DISCHARGE WITH MITIGATION PURPOSES**

**TABLES AND FIGURES**

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Table B-1 Delta (Project – Existing) D.O. Percentiles for Critical Cells: Plan 6a, 6 ft deepening, and mitigation D.O. injections

| Zone | Delta D.O. Percentile |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|------|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|      | 1%                    |       | 5%    |       | 10%   |       | 25%   |       | 50%   |       | 75%   |       | 90%   |       | 95%   |       | 99    |       |
|      | mg/l                  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     |
| FR1  | 0.07                  | 1.8   | 0.06  | 1.5   | 0.06  | 1.2   | 0.06  | 1.4   | 0.03  | 0.7   | 0.04  | 0.9   | 0.01  | 0.2   | -0.02 | -0.4  | 0     | 0.0   |
| FR2  | 0.18                  | 4.9   | 0.17  | 4.5   | 0.16  | 3.9   | 0.18  | 4.5   | 0.17  | 4.0   | 0.14  | 3.2   | 0.12  | 2.6   | 0.13  | 2.5   | -0.22 | -4.3  |
| FR3  | 0.26                  | 7.4   | 0.23  | 6.4   | 0.27  | 7.4   | 0.3   | 7.8   | 0.29  | 7.2   | 0.43  | 10.0  | 0.28  | 5.9   | 0.54  | 10.7  | 0.35  | 6.3   |
| FR4  | 0.28                  | 8.0   | 0.28  | 7.9   | 0.38  | 10.5  | 0.29  | 7.4   | 0.34  | 8.4   | 0.43  | 9.8   | 0.7   | 4.0   | 0.3   | 5.6   | 0.48  | 8.7   |
| FR5  | 0.53                  | 14.6  | 0.57  | 15.2  | 0.54  | 13.9  | 0.52  | 12.7  | 0.56  | 13.0  | 0.33  | 6.7   | 0.14  | 2.6   | 0.09  | 1.6   | 0.19  | 3.3   |
| FR6  | 0.58                  | 15.7  | 0.67  | 17.8  | 0.72  | 18.5  | 0.63  | 15.3  | 0.73  | 17.1  | 0.5   | 10.5  | 0.06  | 1.1   | 0.08  | 1.4   | 0.1   | 1.7   |
| FR7  | 0.51                  | 12.2  | 0.55  | 12.9  | 0.6   | 13.9  | 0.47  | 10.2  | 0.29  | 5.8   | -0.26 | -4.3  | -0.04 | -0.6  | 0.19  | 3.0   | 0.23  | 3.9   |
| FR8  | 0.27                  | 5.8   | 0.24  | 5.0   | 0.08  | 1.6   | -0.11 | -2.0  | -0.13 | -2.1  | -0.01 | -0.2  | 0.03  | 0.4   | 0.04  | 0.6   | -0.08 | -1.1  |
| FR9  | 0.66                  | 13.5  | 0.87  | 17.3  | 0.74  | 13.9  | 0.66  | 11.5  | 0.41  | 6.5   | 0.38  | 5.8   | 0.47  | 6.9   | 0.56  | 8.0   | 0.69  | 9.6   |
| FR10 | 1.83                  | 42.5  | 1.55  | 32.4  | 1.49  | 30.1  | 1.46  | 27.4  | 1.11  | 18.8  | 0.84  | 13.1  | 1.04  | 15.6  | 0.77  | 11.0  | 0.69  | 9.6   |
| FR11 | -1.46                 | -35.0 | -1.99 | -42.3 | -2.21 | -44.8 | -2.5  | -47.7 | -2.89 | -51.0 | -3.25 | -62.9 | -3.47 | -53.4 | -3.53 | -53.2 | -3.95 | -55.4 |
| MR1  | 0.37                  | 8.4   | 0.4   | 8.8   | 0.42  | 9.1   | 0.32  | 6.5   | 0.28  | 5.0   | 0.08  | 1.4   | 0     | 0.0   | 0.03  | 0.5   | -0.04 | -0.6  |
| MR2  | 0.66                  | 16.4  | 0.78  | 18.8  | 0.71  | 16.4  | 0.58  | 12.6  | 0.34  | 6.7   | 0.11  | 2.0   | 0.08  | 1.4   | 0.08  | 1.4   | 0.19  | 3.2   |
| MR3  | 0.98                  | 26.5  | 0.92  | 23.7  | 0.92  | 23.0  | 0.94  | 22.4  | 0.89  | 19.7  | 0.55  | 10.8  | 0.12  | 2.1   | 0.02  | 0.3   | -0.01 | -0.2  |
| MR4  | 0.95                  | 24.4  | 0.91  | 22.6  | 0.92  | 22.3  | 0.91  | 20.7  | 0.87  | 21.0  | 1.08  | 22.1  | 1.21  | 23.9  | 1.27  | 24.5  | 1.3   | 24.0  |
| MR5  | 1.52                  | 102.0 | 1.55  | 16.0  | 1.56  | 84.7  | 1.57  | 51.5  | 1.46  | 28.4  | 0.92  | 14.8  | 1     | 15.2  | 0.85  | 12.3  | 0.75  | 10.5  |
| MR6  | 0.53                  | 25.1  | 0.16  | 6.4   | -0.35 | -11.6 | -0.81 | -23.1 | -2.8  | -49.9 | -3.34 | -52.5 | -3.54 | -52.1 | -3.67 | -52.0 | -3.83 | -52.3 |
| LBR1 | 1.24                  | 34.7  | 1.07  | 24.6  | 1.1   | 23.2  | 1.06  | 20.7  | 1.02  | 18.8  | 1.2   | 21.3  | 1.13  | 18.9  | 1.12  | 18.2  | 1.17  | 18.1  |
| LBR2 | 1.25                  | 33.9  | 1.42  | 36.8  | 1.46  | 36.5  | 1.45  | 34.9  | 1.43  | 32.6  | 1.47  | 32.0  | 1.49  | 31.2  | 1.52  | 31.1  | 1.31  | 24.9  |
| LBR3 | 0.25                  | 8.7   | -0.05 | -1.5  | -0.11 | -3.2  | -0.12 | -3.3  | -0.08 | -2.0  | -0.14 | -3.2  | -0.34 | -7.2  | -0.48 | -9.6  | -0.58 | -11.1 |
| BR1  | 0.29                  | 8.4   | 0.36  | 10.2  | 0.34  | 9.5   | 0.2   | 5.1   | 0.37  | 9.2   | 0.37  | 8.7   | 0.24  | 5.3   | 0.22  | 4.8   | 0.27  | 5.8   |
| BR2  | -0.21                 | -6.2  | 0.25  | 8.8   | 0.27  | 9.0   | 0.3   | 9.3   | 0.47  | 13.7  | 0.49  | 13.2  | 0.55  | 14.3  | 0.5   | 12.7  | 0.54  | 13.4  |
| BR3  | -0.06                 | -2.0  | -0.17 | -5.2  | -0.26 | -7.6  | -0.31 | -8.6  | -0.08 | -2.1  | 0.33  | 8.4   | 0.4   | 9.6   | 0.46  | 11.1  | 0.47  | 11.1  |
| SCH1 | -0.04                 | -1.7  | 0.08  | 3.1   | 0.11  | 4.1   | 0.13  | 4.6   | 0.23  | 7.8   | 0.6   | 17.6  | 0.51  | 13.5  | 0.56  | 14.4  | 0.48  | 11.6  |
| SCH2 | 0.1                   | 2.7   | 0.04  | 1.0   | 0.06  | 1.2   | 0.13  | 3.1   | 0.09  | 2.1   | 0.09  | 2.0   | 0.07  | 1.5   | 0.07  | 1.5   | 0.02  | 0.4   |
| SR   | 1.45                  | 30.9  | 1.51  | 31.9  | 1.48  | 29.8  | 1.52  | 28.6  | 1.44  | 25.6  | 1.37  | 22.9  | 1.69  | 27.7  | 1.75  | 28.4  | 1.78  | 28.6  |
| StbR | 0.2                   | 5.2   | 0.42  | 10.0  | 0.31  | 6.8   | 0.39  | 7.7   | 0.27  | 4.7   | 0.15  | 2.4   | 0.13  | 2.0   | 0.07  | 1.1   | 0.12  | 1.8   |

Table B-2 Delta (Project – Existing) D.O. Percentiles for Critical Cells: Plan 6a, 5 ft deepening, and mitigation D.O. injections

| Zone | Delta D.O. Percentile |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|------|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|      | 1%                    |       | 5%    |       | 10%   |       | 25%   |       | 50%   |       | 75%   |       | 90%   |       | 95%   |       | 99    |       |
|      | mg/l                  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     |
| FR1  | 0.05                  | 1.3   | 0.06  | 1.5   | 0.05  | 1.2   | 0.07  | 1.7   | 0.03  | 0.7   | 0.02  | 0.4   | 0     | 0.0   | -0.02 | -0.4  | -0.03 | -0.6  |
| FR2  | 0.16                  | 4.4   | 0.15  | 4.0   | 0.14  | 3.6   | 0.16  | 4.0   | 0.15  | 3.6   | 0.14  | 3.2   | 0.1   | 2.2   | 0.11  | 2.3   | -0.22 | -4.3  |
| FR3  | 0.23                  | 6.6   | 0.19  | 5.3   | 0.23  | 6.3   | 0.24  | 6.2   | 0.21  | 5.2   | 0.24  | 5.6   | 0.19  | 4.0   | 0.5   | 9.9   | 0.3   | 5.4   |
| FR4  | 0.23                  | 6.6   | 0.24  | 6.7   | 0.29  | 8.0   | 0.21  | 5.4   | 0.23  | 5.7   | 0.22  | 5.0   | 0.03  | 0.6   | 0.16  | 3.0   | 0.45  | 8.2   |
| FR5  | 0.49                  | 13.5  | 0.58  | 15.5  | 0.58  | 14.9  | 0.54  | 13.2  | 0.64  | 14.8  | 0.44  | 9.0   | 0.19  | 3.5   | 0.26  | 4.6   | 0.32  | 5.5   |
| FR6  | 0.46                  | 12.5  | 0.45  | 12.0  | 0.41  | 10.6  | 0.38  | 9.2   | 0.37  | 8.7   | 0.21  | 4.4   | -0.22 | -3.9  | -0.15 | -2.6  | -0.06 | -0.8  |
| FR7  | 0.6                   | 14.4  | 0.65  | 15.3  | 0.7   | 16.2  | 0.69  | 15.0  | 0.82  | 16.3  | 0.35  | 5.9   | 0.4   | 6.4   | 0.57  | 9.0   | 1.07  | 19.5  |
| FR8  | 0.1                   | 2.1   | 0.11  | 2.3   | 0.04  | 0.8   | -0.12 | -2.2  | 0.11  | 1.8   | 0.5   | 4.7   | 0.27  | 4.0   | 0.26  | 3.8   | 0.17  | 2.4   |
| FR9  | 0.4                   | 8.2   | 0.66  | 13.1  | 0.56  | 10.5  | 0.65  | 11.4  | 0.49  | 7.8   | 0.52  | 7.9   | 0.62  | 9.1   | 0.66  | 9.4   | 0.67  | 9.3   |
| FR10 | 1.86                  | 43.2  | 1.59  | 33.3  | 1.57  | 31.7  | 1.53  | 28.3  | 1.17  | 19.8  | 0.81  | 14.2  | 1.1   | 16.5  | 0.84  | 12.0  | 0.75  | 10.4  |
| FR11 | -1.46                 | -35.0 | -1.89 | -42.3 | -2.21 | -44.8 | -2.5  | -47.7 | -2.89 | -51.0 | -3.25 | -62.9 | -3.47 | -53.4 | -3.53 | -53.2 | -3.95 | -55.4 |
| MR1  | 0.18                  | 4.1   | 0.17  | 3.8   | 0.2   | 4.3   | 0.2   | 4.1   | 0.21  | 4.1   | 0.02  | 0.4   | 0.01  | 0.2   | 0.07  | 1.2   | 0.17  | 2.7   |
| MR2  | 0.73                  | 18.1  | 0.76  | 18.3  | 0.65  | 15.0  | 0.54  | 11.7  | 0.32  | 6.3   | 0.08  | 1.4   | 0.13  | 2.2   | 0.15  | 2.5   | 0.19  | 3.2   |
| MR3  | 1.05                  | 28.6  | 1     | 25.7  | 0.97  | 24.3  | 1     | 23.9  | 0.95  | 21.0  | 0.63  | 12.4  | 0.18  | 3.2   | 0.1   | 1.7   | 0.03  | 0.5   |
| MR4  | 1.05                  | 27.0  | 1     | 24.8  | 1.02  | 24.8  | 1.01  | 23.0  | 1.09  | 23.6  | 1.23  | 25.2  | 1.35  | 26.7  | 1.43  | 27.6  | 1.45  | 26.8  |
| MR5  | 1.67                  | 112.1 | 1.74  | 69.3  | 1.67  | 89.3  | 1.72  | 56.4  | 1.63  | 32.8  | 1.15  | 18.5  | 1.24  | 18.9  | 1.06  | 15.4  | 1.01  | 14.2  |
| MR6  | 0.53                  | 25.1  | 0.16  | 6.4   | -0.35 | -11.6 | -0.81 | -23.1 | -2.8  | -49.9 | -3.34 | -52.5 | -3.54 | -52.1 | -3.67 | -52.0 | -3.83 | -52.3 |
| LBR1 | 1.39                  | 38.9  | 1.29  | 29.7  | 1.28  | 28.9  | 1.2   | 23.4  | 1.17  | 21.5  | 1.35  | 23.9  | 1.3   | 21.8  | 1.29  | 20.9  | 1.34  | 20.7  |
| LBR2 | 1.62                  | 43.9  | 1.59  | 41.2  | 1.59  | 40.1  | 1.57  | 37.7  | 1.57  | 35.8  | 1.6   | 34.8  | 1.86  | 34.8  | 1.67  | 34.2  | 1.48  | 28.1  |
| LBR3 | 0.35                  | 12.1  | 0.07  | 2.1   | 0.03  | 0.9   | 0     | 0.0   | 0.07  | 1.8   | -0.03 | -0.7  | -0.22 | -4.7  | -0.37 | -7.4  | -0.47 | -9.0  |
| BR1  | 0.21                  | 6.1   | 0.28  | 8.0   | 0.28  | 7.8   | 0.13  | 3.3   | 0.31  | 7.7   | 0.33  | 7.8   | 0.19  | 4.2   | 0.17  | 3.7   | 0.23  | 4.8   |
| BR2  | 0.31                  | 12.2  | -0.21 | -7.4  | 0.2   | 6.7   | -0.23 | -7.1  | 0.41  | 11.9  | 0.42  | 11.4  | 0.48  | 12.6  | 0.46  | 11.7  | 0.5   | 12.4  |
| BR3  | 0                     | 0.0   | -0.12 | -3.7  | -0.25 | -7.3  | -0.25 | -6.9  | -0.09 | -2.4  | 0.28  | 7.1   | 0.35  | 8.6   | 0.4   | 9.6   | 0.42  | 9.9   |
| SCH1 | 0.02                  | 0.8   | 0     | 0.0   | 0.1   | 3.7   | 0.16  | 5.7   | 0.14  | 4.7   | -0.04 | -1.2  | -0.07 | -1.9  | -0.06 | -1.3  | -0.19 | -4.6  |
| SCH2 | 0.08                  | 2.1   | 0.02  | 0.5   | 0.04  | 1.0   | 0.08  | 1.9   | 0.07  | 1.6   | 0.09  | 2.0   | 0.07  | 1.5   | 0.06  | 1.3   | 0.07  | 1.5   |
| SR   | 1.45                  | 30.9  | 1.51  | 31.9  | 1.49  | 30.0  | 1.53  | 28.6  | 1.45  | 25.3  | 1.37  | 22.9  | 1.7   | 27.8  | 1.75  | 28.4  | 1.79  | 28.7  |
| StbR | 0.33                  | 8.6   | 0.5   | 11.8  | 0.44  | 9.6   | 0.45  | 8.9   | 0.35  | 6.2   | 0.23  | 3.7   | 0.19  | 2.9   | 0.18  | 2.7   | 0.2   | 2.9   |



Table B-3 Delta (Project – Existing) D.O. Percentiles for Critical Cells: Plan 6a, 4 ft deepening, and mitigation D.O. injections

| Zone | Delta D.O. Percentile |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|------|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|      | 1%                    |       | 5%    |       | 10%   |       | 25%   |       | 50%   |       | 75%   |       | 90%   |       | 95%   |       | 99    |       |
|      | mg/l                  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     |
| FR1  | 0.04                  | 1.0   | 0.02  | 0.5   | 0     | 0.0   | 0.04  | 0.9   | 0.01  | 0.2   | 0.03  | 0.7   | 0.04  | 0.9   | 0     | 0.0   | 0.04  | 0.8   |
| FR2  | 0.14                  | 3.8   | 0.14  | 3.7   | 0.13  | 3.4   | 0.16  | 4.0   | 0.14  | 3.3   | 0.14  | 3.2   | 0.1   | 2.2   | 0.13  | 2.8   | -0.21 | -4.1  |
| FR3  | 0.19                  | 5.4   | 0.17  | 4.7   | 0.21  | 5.8   | 0.22  | 5.7   | 0.19  | 4.7   | 0.22  | 5.1   | 0.18  | 3.8   | 0.48  | 9.5   | 0.28  | 5.0   |
| FR4  | 0.2                   | 5.7   | 0.22  | 6.2   | 0.26  | 7.2   | 0.19  | 4.8   | 0.19  | 4.7   | 0.14  | -3.2  | 0.05  | -1.0  | 0.18  | 3.4   | 0.45  | 8.2   |
| FR5  | 0.44                  | 12.2  | 0.54  | 14.4  | 0.52  | 13.4  | 0.49  | 12.0  | 0.58  | 13.5  | 0.4   | 8.2   | 0.19  | 3.5   | 0.27  | 4.8   | 0.34  | 5.9   |
| FR6  | 0.38                  | 10.3  | 0.38  | 9.6   | 0.34  | 8.7   | 0.3   | 7.3   | 0.27  | 6.3   | 0.08  | 1.7   | -0.18 | -3.2  | -0.05 | -0.9  | -0.02 | -0.3  |
| FR7  | 0.82                  | 19.7  | 0.67  | 20.5  | 1.03  | 23.8  | 1.05  | 22.8  | 1.16  | 23.1  | 0.84  | 10.7  | 0.6   | 9.6   | 0.75  | 11.8  | 0.98  | 15.1  |
| FR8  | 0.08                  | 1.7   | 0.1   | 2.1   | 0.01  | 0.2   | -0.14 | -2.5  | 0.17  | 2.8   | 0.3   | 4.7   | 0.29  | 4.3   | 0.29  | 4.2   | 0.15  | 2.1   |
| FR9  | 0.01                  | 0.2   | -0.03 | -0.6  | -0.15 | -2.8  | -0.25 | -4.4  | -0.1  | -1.6  | 0.12  | 1.8   | 0.15  | 2.2   | 0.08  | 1.3   | 0.15  | 2.1   |
| FR10 | 1.85                  | 42.9  | 1.57  | 32.8  | 1.52  | 30.7  | 1.49  | 28.0  | 1.13  | 19.1  | 0.88  | 13.7  | 1.06  | 15.9  | 0.81  | 11.6  | 0.73  | 10.1  |
| FR11 | -1.46                 | -35.0 | -1.99 | -42.3 | -2.21 | -44.8 | -2.5  | -47.7 | -2.89 | -51.0 | -3.25 | -52.9 | -3.47 | -53.4 | -3.53 | -53.2 | -3.95 | -55.4 |
| MR1  | 0.13                  | 2.9   | 0.15  | 3.3   | 0.18  | 3.9   | 0.16  | 3.3   | 0.19  | 3.7   | 0     | 0.0   | 0.05  | 0.8   | 0.09  | 1.5   | 0.21  | 3.4   |
| MR2  | 0.67                  | 16.6  | 0.73  | 17.6  | 0.62  | 14.3  | 0.51  | 11.0  | 0.31  | 6.1   | 0.07  | 1.3   | 0.14  | 2.4   | 0.15  | 2.5   | 0.2   | 3.3   |
| MR3  | 1.03                  | 27.8  | 0.96  | 24.7  | 0.95  | 23.3  | 0.97  | 23.2  | 0.92  | 20.4  | 0.6   | 11.8  | 0.13  | 2.3   | 0.1   | 1.7   | 0.01  | 0.2   |
| MR4  | 1.02                  | 26.2  | 0.98  | 23.8  | 0.99  | 24.0  | 0.97  | 22.1  | 1.04  | 22.6  | 1.16  | 23.7  | 1.29  | 25.5  | 1.3   | 25.1  | 1.34  | 24.8  |
| MR5  | 1.6                   | 107.4 | 1.65  | 80.9  | 1.61  | 66.3  | 1.63  | 53.4  | 1.55  | 31.2  | 1.03  | 16.5  | 1.12  | 17.0  | 0.94  | 13.6  | 0.87  | 12.2  |
| MR6  | 0.53                  | 25.1  | 0.16  | 6.4   | -0.35 | -11.6 | -0.81 | -33.1 | -2.8  | -49.9 | -3.34 | -52.5 | -3.54 | -52.1 | -3.67 | -52.0 | -3.83 | -52.3 |
| LBR1 | 1.28                  | 35.9  | 1.26  | 29.0  | 1.18  | 24.8  | 1.11  | 21.6  | 1.09  | 20.1  | 1.27  | 22.5  | 1.21  | 20.3  | 1.2   | 19.5  | 1.23  | 19.0  |
| LBR2 | 0.57                  | 15.4  | 1.5   | 36.9  | 1.51  | 38.0  | 1.5   | 36.1  | 1.5   | 34.2  | 1.52  | 33.0  | 1.56  | 32.5  | 1.57  | 32.2  | 1.39  | 26.4  |
| LBR3 | 0.32                  | 11.1  | 0.01  | 0.3   | -0.02 | -0.6  | -0.05 | -1.6  | -0.01 | -0.3  | -0.1  | -2.3  | -0.28 | -3.9  | -0.46 | -3.2  | -0.5  | -3.5  |
| BR1  | 0.16                  | 4.6   | 0.2   | 5.7   | 0.21  | 5.8   | 0.08  | 1.5   | 0.28  | 6.9   | 0.31  | 7.3   | 0.16  | 3.5   | 0.14  | 3.0   | 0.2   | 4.3   |
| BR2  | 0.15                  | 5.9   | 0.12  | 4.2   | 0.13  | 4.3   | 0.14  | 4.3   | 0.35  | 10.2  | 0.38  | 10.5  | 0.44  | 11.5  | 0.43  | 10.9  | 0.48  | 11.4  |
| BR3  | -0.06                 | -2.0  | -0.2  | -6.1  | -0.32 | -9.3  | -0.32 | -8.6  | -0.17 | -4.5  | 0.23  | 5.8   | 0.3   | 7.4   | 0.36  | 8.7   | 0.36  | 8.5   |
| SCH1 | -0.05                 | -2.1  | 0.07  | 2.7   | 0.1   | 3.7   | 0.12  | 4.2   | 0.23  | 7.6   | 0.68  | 19.4  | 0.57  | 15.1  | 0.59  | 15.2  | 0.48  | 11.6  |
| SCH2 | 0.07                  | 1.9   | -0.02 | -0.5  | 0.04  | 1.0   | 0.09  | 2.2   | 0.07  | 1.6   | 0.09  | 2.0   | 0.08  | 1.7   | 0.09  | 1.9   | 0.07  | 1.5   |
| SR   | 1.45                  | 30.9  | 1.51  | 31.9  | 1.48  | 29.8  | 1.52  | 26.6  | 1.44  | 25.6  | 1.37  | 22.9  | 1.7   | 27.8  | 1.75  | 28.4  | 1.78  | 28.6  |
| StdR | 0.35                  | 9.1   | 0.44  | 10.4  | 0.42  | 9.2   | 0.45  | 8.9   | 0.3   | 5.3   | 0.24  | 3.9   | 0.18  | 2.6   | 0.18  | 2.7   | 0.15  | 2.2   |

Table B-4 Delta (Project – Existing) D.O. Percentiles for Critical Cells: Plan 6a, 3 ft deepening, and mitigation D.O. injections

| Zone | Delta D.O. Percentile |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|------|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|      | 1%                    |       | 5%    |       | 10%   |       | 25%   |       | 50%   |       | 75%   |       | 90%   |       | 95%   |       | 99    |       |
|      | mg/l                  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     |
| FR1  | 0.05                  | 1.3   | 0.03  | 0.8   | 0.01  | 0.2   | 0.03  | 0.7   | 0.01  | 0.2   | 0.05  | 1.1   | 0.06  | 1.3   | 0.03  | 0.6   | 0.06  | 1.3   |
| FR2  | 0.15                  | 4.1   | 0.15  | 4.0   | 0.12  | 3.1   | 0.17  | 4.2   | 0.16  | 3.8   | 0.13  | 3.0   | 0.14  | 3.0   | 0.17  | 3.6   | -0.19 | -3.7  |
| FR3  | 0.19                  | 5.4   | 0.16  | 4.5   | 0.17  | 4.7   | 0.22  | 5.7   | 0.2   | 4.9   | 0.21  | 4.9   | 0.21  | 4.4   | 0.48  | 9.5   | 0.27  | 4.8   |
| FR4  | 0.2                   | 5.7   | 0.19  | 5.3   | 0.21  | 5.8   | 0.2   | 5.1   | 0.19  | 4.7   | 0.14  | 3.2   | 0.13  | 2.6   | 0.2   | 3.8   | 0.43  | 7.8   |
| FR5  | 0.31                  | 8.6   | 0.27  | 7.2   | 0.22  | 5.7   | 0.24  | 5.9   | 0.18  | 3.7   | -0.13 | -2.7  | 0.01  | 0.2   | 0.05  | 0.9   | 0.15  | 2.6   |
| FR6  | 0.27                  | 7.3   | 0.28  | 7.4   | 0.23  | 5.9   | 0.33  | 8.6   | 0.22  | 5.2   | -0.01 | -0.2  | -0.05 | -0.9  | 0.05  | 0.9   | 0.07  | 1.2   |
| FR7  | 0.6                   | 14.4  | 0.62  | 14.6  | 0.69  | 15.9  | 0.67  | 14.5  | 0.81  | 16.1  | 0.4   | 6.7   | 0.42  | 6.7   | 0.53  | 8.3   | 1.04  | 16.0  |
| FR8  | 0.09                  | 1.7   | 0.11  | 2.3   | 0.03  | 0.6   | -0.08 | -1.5  | 0.22  | 3.6   | 0.35  | 5.4   | 0.32  | 4.8   | 0.3   | 4.4   | 0.24  | 3.4   |
| FR9  | 0.02                  | 0.4   | -0.03 | -0.6  | -0.1  | -1.9  | -0.15 | -2.6  | 0.06  | 1.0   | 0.28  | 4.2   | 0.25  | 3.6   | 0.22  | 3.1   | 0.37  | 5.1   |
| FR10 | 1.84                  | 42.7  | 1.57  | 32.8  | 1.52  | 30.7  | 1.48  | 27.8  | 1.14  | 19.3  | 0.88  | 13.7  | 1.06  | 15.9  | 0.81  | 11.6  | 0.72  | 10.0  |
| FR11 | -1.46                 | -35.0 | -1.99 | -42.3 | -2.21 | -44.8 | -2.5  | -47.7 | -2.89 | -51.0 | -3.25 | -52.9 | -3.47 | -53.4 | -3.53 | -53.2 | -3.95 | -55.4 |
| MR1  | 0.11                  | 2.5   | 0.11  | 2.4   | 0.17  | 3.7   | 0.15  | 3.1   | 0.2   | 3.9   | 0.02  | 0.4   | 0.1   | 1.7   | 0.16  | 2.7   | 0.27  | 4.3   |
| MR2  | 0.7                   | 17.4  | 0.71  | 17.1  | 0.65  | 15.0  | 0.58  | 12.6  | 0.41  | 8.1   | 0.2   | 3.6   | 0.19  | 3.3   | 0.25  | 4.2   | 0.19  | 3.2   |
| MR3  | 1.02                  | 27.6  | 0.98  | 25.2  | 0.95  | 23.8  | 0.96  | 22.9  | 0.95  | 21.0  | 0.62  | 12.2  | 0.17  | 3.0   | 0.12  | 2.0   | 0.03  | 0.5   |
| MR4  | 1.01                  | 26.0  | 0.98  | 23.8  | 1     | 24.3  | 0.96  | 21.9  | 1.04  | 22.6  | 1.14  | 23.3  | 1.26  | 24.9  | 1.31  | 25.3  | 1.33  | 24.6  |
| MR5  | 1.6                   | 107.4 | 1.68  | 82.4  | 1.6   | 66.4  | 1.63  | 53.4  | 1.56  | 31.4  | 1.03  | 16.5  | 1.12  | 17.0  | 0.94  | 13.6  | 0.87  | 12.2  |
| MR6  | 0.53                  | 25.1  | 0.16  | 6.4   | -0.35 | -11.6 | -0.81 | -33.1 | -2.8  | -49.9 | -3.34 | -52.5 | -3.54 | -52.1 | -3.67 | -52.0 | -3.83 | -52.3 |
| LBR1 | 1.26                  | 35.3  | 1.27  | 29.2  | 1.2   | 25.3  | 1.1   | 21.4  | 1.09  | 20.1  | 1.27  | 22.5  | 1.21  | 20.3  | 1.2   | 19.5  | 1.23  | 19.0  |
| LBR2 | 1.6                   | 43.4  | 1.5   | 36.9  | 1.53  | 38.5  | 1.5   | 36.1  | 1.49  | 33.9  | 1.53  | 33.3  | 1.58  | 33.1  | 1.64  | 33.6  | 2.14  | 40.7  |
| LBR3 | 0.33                  | 11.4  | 0.02  | 0.6   | 0     | 0.0   | -0.04 | -1.1  | 0.02  | 0.5   | -0.06 | -1.4  | -0.28 | -3.9  | -0.42 | -3.4  | -0.52 | -3.9  |
| BR1  | 0.12                  | 3.5   | 0.19  | 5.4   | 0.19  | 5.3   | 0.04  | 1.0   | 0.24  | 6.0   | 0.29  | 6.8   | 0.15  | 3.3   | 0.13  | 2.8   | 0.10  | 4.1   |
| BR2  | 0.18                  | 7.1   | 0.07  | 2.5   | 0.09  | 3.0   | 0.12  | 3.7   | 0.31  | 9.0   | 0.36  | 9.7   | 0.41  | 10.7  | 0.39  | 9.9   | 0.44  | 10.9  |
| BR3  | -0.06                 | -2.0  | -0.17 | -5.2  | -0.28 | -6.1  | -0.32 | -8.6  | -0.22 | -5.8  | 0.04  | 1.0   | 0.12  | 2.9   | 0.16  | 3.9   | 0.23  | 5.4   |
| SCH1 | -0.09                 | -3.6  | 0.07  | 2.7   | 0.08  | 2.2   | 0.1   | 3.5   | 0.25  | 8.3   | 0.66  | 19.4  | 0.59  | 15.6  | 0.58  | 14.9  | 0.46  | 11.8  |
| SCH2 | 0.1                   | 2.7   | 0.04  | 1.0   | 0.08  | 2.0   | 0.07  | 1.7   | 0.07  | 1.6   | 0.07  | 1.6   | 0.04  | 0.9   | 0.09  | 1.1   | 0.06  | 1.2   |
| SR   | 1.45                  | 30.9  | 1.51  | 31.9  | 1.49  | 30.0  | 1.53  | 28.8  | 1.44  | 25.6  | 1.37  | 22.9  | 1.7   | 27.8  | 1.75  | 28.4  | 1.78  | 28.6  |
| StdR | 0.45                  | 11.7  | 0.48  | 11.4  | 0.46  | 10.1  | 0.47  | 9.3   | 0.31  | 5.4   | 0.27  | 4.4   | 0.21  | 3.2   | 0.22  | 3.3   | 0.23  | 3.4   |



Table B-5 Delta (Project – Existing) D.O. Percentiles for Critical Cells: Plan 6b, 2 ft deepening, and mitigation D.O. injections

| Zone | Delta D.O. Percentile |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|------|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|      | 1%                    |       | 5%    |       | 10%   |       | 25%   |       | 50%   |       | 75%   |       | 90%   |       | 95%   |       | 99    |       |
|      | mg/l                  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     | mg/l  | %     |
| FR1  | 0.03                  | 0.8   | 0.02  | 0.5   | 0     | 0.0   | 0.05  | 1.2   | 0.03  | 0.7   | 0.08  | 1.8   | 0.09  | 1.9   | 0.06  | 1.7   | 0.11  | 2.3   |
| FR2  | 0.14                  | 3.8   | 0.14  | 3.7   | 0.13  | 3.4   | 0.19  | 4.7   | 0.17  | 4.0   | 0.17  | 3.9   | 0.23  | 5.0   | 0.22  | 4.7   | 0.08  | -1.8  |
| FR3  | 0.2                   | 5.7   | 0.15  | 4.2   | 0.17  | 4.7   | 0.22  | 5.7   | 0.22  | 5.4   | 0.28  | 6.5   | 0.38  | 7.9   | 0.53  | 10.5  | 0.35  | 6.3   |
| FR4  | 0.2                   | 5.7   | 0.19  | 5.3   | 0.22  | 6.1   | 0.27  | 5.1   | 0.23  | 5.7   | 0.23  | 5.2   | 0.2   | 4.0   | 0.26  | 4.9   | 0.38  | 6.5   |
| FR5  | 0.29                  | 8.0   | 0.25  | 6.7   | 0.29  | 7.5   | 0.27  | 6.6   | 0.24  | 5.6   | 0.03  | -0.6  | 0.21  | 3.9   | 0.29  | 5.2   | 0.28  | 4.8   |
| FR6  | 0.26                  | 7.0   | 0.29  | 7.7   | 0.25  | 6.4   | 0.26  | 6.3   | 0.27  | 6.3   | 0.08  | 1.7   | 0.11  | 2.0   | 0.17  | 2.9   | 0.16  | 2.7   |
| FR7  | 0.65                  | 15.6  | 0.88  | 16.0  | 0.76  | 17.6  | 0.76  | 16.5  | 0.91  | 18.1  | 0.47  | 7.9   | 0.46  | 7.3   | 0.52  | 6.2   | 0.87  | 13.4  |
| FR8  | 0.12                  | 2.6   | 0.11  | 2.3   | 0     | 0.0   | -0.07 | -1.3  | 0.17  | 2.8   | 0.22  | 3.4   | 0.17  | 2.5   | 0.16  | 2.3   | 0.11  | 1.5   |
| FR9  | 0.61                  | 12.5  | 0.92  | 18.3  | 0.81  | 15.2  | 0.8   | 14.0  | 0.56  | 8.9   | 0.53  | 8.0   | 0.63  | 9.2   | 0.59  | 8.4   | 0.84  | 8.9   |
| FR10 | 1.85                  | 42.9  | 1.59  | 33.3  | 1.52  | 30.7  | 1.51  | 28.4  | 1.15  | 19.5  | 0.89  | 13.8  | 1.08  | 16.2  | 0.82  | 11.7  | 0.72  | 10.0  |
| FR11 | -1.46                 | -35.0 | -1.99 | -42.3 | -2.21 | -44.8 | -2.5  | -47.7 | -2.89 | -51.0 | -3.25 | -52.9 | -3.47 | -53.4 | -3.53 | -53.2 | -3.95 | -55.4 |
| MR1  | -0.15                 | -3.4  | -0.16 | -3.5  | -0.21 | -4.5  | -0.19 | -3.9  | -0.21 | -4.1  | -0.09 | -1.6  | -0.2  | -3.4  | -0.24 | -4.0  | -0.31 | -5.0  |
| MR2  | 0.66                  | 16.4  | 0.67  | 16.1  | 0.6   | 13.9  | 0.53  | 11.5  | 0.36  | 7.1   | 0.17  | 3.1   | 0.27  | 4.7   | 0.28  | 4.7   | 0.32  | 5.3   |
| MR3  | 0.54                  | 25.4  | 0.88  | 22.6  | 0.86  | 21.5  | 0.86  | 20.6  | 0.85  | 18.8  | 0.55  | 10.8  | 0.2   | 3.5   | 0.17  | 2.9   | 0.08  | -1.9  |
| MR4  | 0.87                  | 22.4  | 1.4   | 34.7  | 1.48  | 35.9  | 1.51  | 34.4  | 1.58  | 34.3  | 1.72  | 35.2  | 1.89  | 37.4  | 2.01  | 38.8  | 2.3   | 42.5  |
| MR5  | 0.86                  | 57.7  | 0.51  | 25.0  | 0.41  | 17.0  | 0.47  | 15.4  | 1.38  | 27.8  | 1.04  | 16.7  | 1.12  | 17.0  | 0.97  | 14.1  | 0.86  | 12.1  |
| MR6  | 3.7                   | 175.4 | 3.69  | 148.2 | 3.38  | 112.3 | 3.13  | 89.2  | 1.27  | 22.6  | 0.74  | 11.6  | 0.56  | 8.2   | 0.41  | 5.8   | 0.33  | 4.5   |
| LBR1 | 0.53                  | 14.8  | 0.71  | 16.3  | 0.95  | 20.0  | 0.9   | 17.5  | 0.85  | 15.8  | 1.04  | 18.4  | 1.05  | 17.8  | 1.05  | 17.0  | 1.23  | 19.0  |
| LBR2 | 0.75                  | 20.3  | 0.96  | 24.9  | 0.95  | 23.9  | 0.96  | 23.1  | 0.93  | 21.2  | 0.97  | 21.1  | 1     | 21.0  | 1.05  | 21.5  | 1.31  | 24.9  |
| LBR3 | -0.28                 | -8.7  | -0.54 | -16.5 | -0.67 | -19.3 | -0.65 | -17.9 | -0.68 | -16.7 | -0.67 | -15.4 | -0.82 | -17.3 | -0.95 | -19.0 | -1.09 | -20.8 |
| BR1  | 0.31                  | 9.0   | 0.47  | 13.4  | 0.59  | 16.4  | 0.41  | 10.5  | 0.48  | 11.9  | 0.46  | 10.8  | 0.31  | 6.8   | 0.33  | 7.1   | 0.45  | 9.6   |
| BR2  | 0.44                  | 17.3  | 0.42  | 14.8  | 0.57  | 19.1  | 0.62  | 19.1  | 0.76  | 22.1  | 0.71  | 19.2  | 0.73  | 19.0  | 0.73  | 18.6  | 0.86  | 21.3  |
| BR3  | -0.44                 | -14.5 | -0.57 | -17.5 | -0.66 | -19.2 | -0.67 | -18.5 | -0.25 | -6.6  | 1.15  | 29.1  | 1.49  | 36.5  | 1.61  | 38.8  | 1.82  | 42.8  |
| SCH1 | 0.04                  | 1.7   | 0.02  | 0.8   | 0.08  | 3.0   | 0.1   | 3.5   | 0.11  | 3.7   | -0.04 | -1.2  | -0.07 | -1.9  | -0.01 | -0.3  | -0.09 | -2.2  |
| SCH2 | 0.11                  | 2.9   | 0.08  | 2.0   | 0.09  | 2.2   | 0.08  | 1.9   | 0.07  | 1.6   | 0.09  | 2.0   | 0.08  | 1.7   | 0.07  | 1.5   | 0.09  | 1.9   |
| SR   | 1.45                  | 30.9  | 1.51  | 31.9  | 1.48  | 29.8  | 1.52  | 28.6  | 1.44  | 26.6  | 1.37  | 22.9  | 1.7   | 27.8  | 1.75  | 28.4  | 1.78  | 28.6  |
| StbR | 0.54                  | 14.1  | 0.59  | 14.0  | 0.5   | 10.9  | 0.52  | 10.3  | 0.37  | 6.5   | 0.29  | 4.7   | 0.26  | 4.0   | 0.26  | 3.9   | 0.3   | 4.4   |

Table B-6 Delta (Project – Existing) D.O. Percentiles for Zones' Averages: Plan 6a, 6 ft deepening, and mitigation D.O. injections

| Zone Name | Project - Baseline Difference (mg/l) |       |       |       |       |       |       |       |       |      | Project - Baseline Relative Difference (%) |      |      |       |       |       |       |       |     |  |
|-----------|--------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|------|--------------------------------------------|------|------|-------|-------|-------|-------|-------|-----|--|
|           | 1%                                   | 5%    | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   |      | 1%                                         | 5%   | 10%  | 25%   | 50%   | 75%   | 90%   | 95%   | 99% |  |
| FR1       | 0.10                                 | 0.08  | 0.08  | 0.12  | 0.09  | 0.07  | 0.04  | 0.04  | 0.00  | 2.3  | 1.8                                        | 1.7  | 2.6  | 1.9   | 1.4   | 0.9   | 0.8   | 0.1   |     |  |
| FR2       | 0.24                                 | 0.20  | 0.17  | 0.22  | 0.17  | 0.19  | 0.17  | 0.17  | 0.18  | 5.7  | 4.9                                        | 3.9  | 5.0  | 3.6   | 4.1   | 3.4   | 3.5   | 3.6   |     |  |
| FR3       | 0.21                                 | 0.24  | 0.25  | 0.28  | 0.26  | 0.22  | 0.21  | 0.15  | 0.09  | 5.2  | 5.9                                        | 6.0  | 6.4  | 5.6   | 4.6   | 4.2   | 2.9   | 1.7   |     |  |
| FR4       | 0.31                                 | 0.37  | 0.40  | 0.40  | 0.46  | 0.46  | 0.35  | 0.23  | 0.20  | 7.6  | 6.8                                        | 9.6  | 9.1  | 10.2  | 9.4   | 6.6   | 4.2   | 3.5   |     |  |
| FR5       | 0.42                                 | 0.45  | 0.50  | 0.46  | 0.50  | 0.32  | 0.13  | 0.06  | 0.12  | 10.2 | 10.6                                       | 11.6 | 10.2 | 10.6  | 6.2   | 2.4   | 1.0   | 2.0   |     |  |
| FR6       | 0.54                                 | 0.53  | 0.48  | 0.42  | 0.29  | 0.05  | -0.08 | 0.03  | 0.08  | 12.9 | 12.3                                       | 10.6 | 8.9  | 5.8   | 0.8   | -1.1  | 0.5   | 1.3   |     |  |
| FR7       | 0.37                                 | 0.31  | 0.26  | 0.19  | -0.05 | 0.03  | 0.05  | 0.01  | -0.03 | 8.0  | 6.5                                        | 5.3  | 3.5  | -0.8  | 0.5   | 0.8   | 0.1   | -0.5  |     |  |
| FR8       | 0.25                                 | 0.10  | 0.14  | 0.02  | 0.01  | -0.11 | 0.13  | 0.03  | 0.12  | 4.8  | 1.9                                        | 2.6  | 0.4  | 0.2   | 1.7   | 1.9   | 0.5   | 1.7   |     |  |
| FR9       | -0.02                                | 0.03  | 0.00  | 0.05  | 0.14  | 0.18  | 0.16  | 0.23  | 0.27  | -0.4 | 0.4                                        | 0.0  | 0.8  | 2.1   | 2.5   | 2.2   | 3.1   | 3.6   |     |  |
| FR10      | 0.44                                 | 0.43  | 0.38  | 0.41  | 0.41  | 0.40  | 0.47  | 0.51  | 0.59  | 7.5  | 7.1                                        | 6.1  | 6.4  | 6.1   | 5.7   | 6.5   | 7.0   | 8.0   |     |  |
| FR11      | 0.48                                 | 0.43  | 0.42  | 0.39  | 0.35  | 0.32  | 0.40  | 0.42  | 0.46  | 8.3  | 7.4                                        | 7.0  | 6.1  | 5.3   | 4.6   | 5.5   | 5.8   | 6.2   |     |  |
| MR1       | 0.38                                 | 0.41  | 0.38  | 0.35  | 0.28  | 0.18  | 0.15  | 0.15  | 0.11  | 8.0  | 8.4                                        | 7.2  | 6.8  | 5.1   | 3.0   | 2.4   | 2.4   | 1.7   |     |  |
| MR2       | 0.57                                 | 0.57  | 0.50  | 0.45  | 0.37  | 0.22  | 0.17  | 0.15  | 0.18  | 12.3 | 11.9                                       | 10.1 | 8.6  | 6.7   | 3.7   | 2.9   | 2.4   | 2.9   |     |  |
| MR3       | 0.85                                 | 0.78  | 0.75  | 0.73  | 0.65  | 0.45  | 0.32  | 0.31  | 0.34  | 18.6 | 16.5                                       | 15.5 | 14.3 | 11.9  | 7.7   | 5.2   | 4.9   | 5.3   |     |  |
| MR4       | 0.75                                 | 0.74  | 0.75  | 0.79  | 0.77  | 0.81  | 0.91  | 1.02  | 1.01  | 15.1 | 14.4                                       | 14.4 | 14.6 | 13.7  | 13.8  | 14.9  | 16.6  | 16.2  |     |  |
| MR5       | 1.01                                 | 1.06  | 1.06  | 1.02  | 0.87  | 0.68  | 0.72  | 0.65  | 0.63  | 24.0 | 23.6                                       | 22.7 | 20.2 | 15.1  | 10.5  | 10.5  | 9.2   | 8.7   |     |  |
| MR6       | 0.08                                 | -0.02 | -0.12 | -0.22 | -0.70 | -0.94 | -1.25 | -1.28 | -1.36 | 1.8  | -0.4                                       | -2.5 | -4.3 | -11.9 | -14.5 | -18.0 | -17.9 | -18.5 |     |  |
| LBR1      | 0.81                                 | 0.87  | 0.91  | 0.91  | 0.93  | 0.97  | 1.11  | 1.12  | 1.13  | 19.0 | 17.4                                       | 18.0 | 17.2 | 16.8  | 17.0  | 18.8  | 18.7  | 18.6  |     |  |
| LBR2      | 1.05                                 | 1.01  | 1.01  | 1.06  | 1.05  | 1.09  | 1.22  | 1.22  | 1.22  | 23.6 | 22.1                                       | 21.7 | 21.9 | 20.7  | 20.9  | 23.1  | 22.6  | 22.2  |     |  |
| LBR3      | 0.43                                 | 0.55  | 0.58  | 0.60  | 0.64  | 0.77  | 0.88  | 0.94  | 1.07  | 10.4 | 12.9                                       | 13.5 | 13.5 | 13.5  | 15.8  | 17.9  | 18.7  | 21.2  |     |  |
| BR1       | 0.38                                 | 0.48  | 0.42  | 0.49  | 0.51  | 0.48  | 0.46  | 0.42  | 0.42  | 10.1 | 12.5                                       | 10.7 | 11.8 | 11.7  | 10.7  | 9.7   | 8.9   | 8.6   |     |  |
| BR2       | 0.37                                 | 0.38  | 0.39  | 0.39  | 0.41  | 0.55  | 0.59  | 0.43  | 0.41  | 10.2 | 10.4                                       | 10.3 | 10.2 | 10.1  | 13.2  | 13.5  | 9.4   | 8.7   |     |  |
| BR3       | 0.07                                 | 0.15  | 0.17  | 0.19  | 0.16  | 0.16  | 0.21  | 0.29  | 0.29  | 1.9  | 4.0                                        | 4.4  | 4.8  | 3.6   | 3.9   | 4.8   | 6.7   | 6.7   |     |  |
| SCH1      | -0.09                                | 0.11  | 0.17  | 0.14  | 0.14  | 0.07  | 0.05  | 0.06  | 0.04  | -2.2 | 2.6                                        | 2.5  | 3.2  | 3.1   | 1.5   | 1.1   | 1.2   | 0.9   |     |  |
| SCH2      | 0.15                                 | 0.17  | 0.14  | 0.16  | 0.18  | 0.14  | 0.13  | 0.11  | 0.08  | 3.4  | 3.6                                        | 3.2  | 3.4  | 3.7   | 2.8   | 2.5   | 2.3   | 1.6   |     |  |
| SR        | 0.98                                 | 0.98  | 0.92  | 0.93  | 0.90  | 0.85  | 1.12  | 1.10  | 1.15  | 16.3 | 16.5                                       | 14.9 | 14.2 | 13.2  | 12.0  | 15.0  | 14.6  | 15.1  |     |  |
| StbR      | 0.26                                 | 0.34  | 0.31  | 0.27  | 0.25  | 0.19  | 0.15  | 0.09  | 0.07  | 4.9  | 6.4                                        | 5.6  | 4.7  | 4.1   | 3.0   | 2.4   | 1.3   | 1.1   |     |  |

Table B-7 Delta (Project – Existing) D.O. Percentiles for Zones' Averages: Plan 6a, 5 ft deepening, and mitigation D.O. injections

| Zone Name | Project - Baseline Difference (mg/l) |      |       |       |       |       |       |       |       | Project - Baseline Relative Difference (%) |      |      |      |       |       |       |       |       |
|-----------|--------------------------------------|------|-------|-------|-------|-------|-------|-------|-------|--------------------------------------------|------|------|------|-------|-------|-------|-------|-------|
|           | 1%                                   | 5%   | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   | 1%                                         | 5%   | 10%  | 25%  | 50%   | 75%   | 90%   | 95%   | 99%   |
| FR1       | 0.08                                 | 0.07 | 0.06  | 0.09  | 0.07  | 0.05  | 0.03  | 0.02  | 0.00  | 1.9                                        | 1.5  | 1.4  | 2.0  | 1.5   | 1.2   | 0.6   | 0.5   | 0.1   |
| FR2       | 0.22                                 | 0.19 | 0.16  | 0.19  | 0.15  | 0.18  | 0.14  | 0.14  | 0.14  | 5.3                                        | 4.4  | 3.7  | 4.3  | 3.4   | 3.8   | 2.9   | 2.8   | 2.8   |
| FR3       | 0.18                                 | 0.21 | 0.20  | 0.23  | 0.22  | 0.17  | 0.16  | 0.08  | 0.01  | 4.4                                        | 5.2  | 4.8  | 5.3  | 4.9   | 3.6   | 3.3   | 1.5   | 0.2   |
| FR4       | 0.23                                 | 0.26 | 0.31  | 0.29  | 0.29  | 0.24  | 0.12  | 0.06  | 0.03  | 5.7                                        | 6.2  | 7.3  | 6.6  | 6.4   | 4.9   | 2.3   | 1.1   | 0.6   |
| FR5       | 0.29                                 | 0.30 | 0.33  | 0.30  | 0.30  | 0.12  | -0.04 | -0.02 | 0.01  | 7.0                                        | 7.0  | 7.6  | 6.7  | 6.3   | 2.4   | -0.8  | -0.3  | 0.2   |
| FR6       | 0.29                                 | 0.28 | 0.26  | 0.22  | 0.11  | -0.05 | -0.11 | 0.06  | 0.12  | 6.9                                        | 6.6  | 5.6  | 4.6  | 2.3   | -1.0  | -1.8  | 1.0   | 1.9   |
| FR7       | 0.20                                 | 0.14 | 0.12  | 0.04  | -0.07 | 0.09  | 0.12  | 0.09  | 0.04  | 4.2                                        | 2.8  | 2.4  | 0.7  | -1.2  | 1.4   | 1.8   | 1.3   | 0.6   |
| FR8       | 0.14                                 | 0.01 | 0.04  | -0.01 | 0.07  | 0.18  | 0.20  | 0.12  | 0.23  | 2.6                                        | 0.2  | 0.8  | -0.3 | 1.1   | 2.8   | 3.0   | 1.7   | 3.3   |
| FR9       | -0.01                                | 0.05 | 0.05  | 0.13  | 0.22  | 0.26  | 0.23  | 0.32  | 0.37  | -0.2                                       | 0.9  | 0.8  | 2.0  | 3.3   | 3.8   | 3.2   | 4.3   | 5.0   |
| FR10      | 0.54                                 | 0.52 | 0.48  | 0.51  | 0.50  | 0.50  | 0.57  | 0.63  | 0.72  | 9.2                                        | 8.6  | 7.9  | 7.9  | 7.5   | 7.2   | 7.9   | 8.6   | 9.8   |
| FR11      | 0.63                                 | 0.58 | 0.56  | 0.55  | 0.50  | 0.46  | 0.56  | 0.60  | 0.64  | 11.1                                       | 10.0 | 9.4  | 8.6  | 7.6   | 6.6   | 7.7   | 8.3   | 8.7   |
| MR1       | 0.22                                 | 0.27 | 0.28  | 0.29  | 0.28  | 0.20  | 0.20  | 0.19  | 0.18  | 4.7                                        | 5.6  | 5.5  | 5.6  | 5.1   | 3.3   | 3.3   | 3.1   | 2.8   |
| MR2       | 0.53                                 | 0.55 | 0.49  | 0.48  | 0.40  | 0.28  | 0.24  | 0.21  | 0.24  | 11.4                                       | 11.6 | 10.0 | 9.2  | 7.3   | 4.8   | 3.9   | 3.4   | 3.8   |
| MR3       | 0.89                                 | 0.86 | 0.82  | 0.82  | 0.73  | 0.52  | 0.40  | 0.39  | 0.45  | 19.5                                       | 18.2 | 16.9 | 16.0 | 13.4  | 8.9   | 6.5   | 6.3   | 7.1   |
| MR4       | 0.86                                 | 0.85 | 0.86  | 0.88  | 0.88  | 0.92  | 1.01  | 1.13  | 1.16  | 17.4                                       | 16.7 | 16.4 | 16.4 | 15.5  | 15.7  | 16.7  | 18.5  | 18.6  |
| MR5       | 1.13                                 | 1.18 | 1.12  | 1.12  | 1.01  | 0.80  | 0.66  | 0.80  | 0.80  | 26.9                                       | 26.3 | 25.3 | 22.3 | 17.5  | 12.4  | 12.7  | 11.3  | 11.1  |
| MR6       | 0.11                                 | 0.01 | -0.10 | -0.21 | -0.68 | -0.91 | -1.22 | -1.25 | -1.31 | 2.6                                        | 0.2  | -2.1 | -4.2 | -11.6 | -14.1 | -17.5 | -17.6 | -17.8 |
| LBR1      | 1.02                                 | 1.01 | 1.03  | 1.03  | 1.04  | 1.08  | 1.22  | 1.25  | 1.26  | 21.5                                       | 20.1 | 20.3 | 19.4 | 18.9  | 18.9  | 20.8  | 20.9  | 20.7  |
| LBR2      | 1.16                                 | 1.13 | 1.14  | 1.16  | 1.16  | 1.20  | 1.34  | 1.33  | 1.38  | 26.2                                       | 24.7 | 24.5 | 24.1 | 23.0  | 23.0  | 25.3  | 24.7  | 25.2  |
| LBR3      | 0.56                                 | 0.66 | 0.69  | 0.71  | 0.74  | 0.88  | 0.99  | 1.05  | 1.17  | 13.4                                       | 15.7 | 16.2 | 15.8 | 15.6  | 18.2  | 20.1  | 21.0  | 23.2  |
| BR1       | 0.33                                 | 0.42 | 0.37  | 0.43  | 0.46  | 0.45  | 0.43  | 0.39  | 0.38  | 8.8                                        | 11.1 | 9.2  | 10.4 | 10.6  | 10.0  | 9.1   | 8.3   | 7.7   |
| BR2       | 0.35                                 | 0.36 | 0.38  | 0.36  | 0.36  | 0.49  | 0.53  | 0.58  | 0.36  | 9.7                                        | 9.8  | 10.1 | 9.4  | 9.1   | 11.8  | 12.2  | 8.3   | 7.7   |
| BR3       | 0.11                                 | 0.18 | 0.19  | 0.23  | 0.19  | 0.20  | 0.29  | 0.38  | 0.39  | 2.9                                        | 4.8  | 5.0  | 5.8  | 4.7   | 4.7   | 6.8   | 8.6   | 8.8   |
| SCh1      | 0.07                                 | 0.09 | 0.09  | 0.12  | 0.11  | 0.07  | 0.06  | 0.06  | 0.05  | 1.6                                        | 2.2  | 2.0  | 2.8  | 2.5   | 1.5   | 1.3   | 1.3   | 1.2   |
| SCh2      | 0.14                                 | 0.15 | 0.13  | 0.14  | 0.15  | 0.12  | 0.11  | 0.11  | 0.10  | 3.2                                        | 3.4  | 2.9  | 2.9  | 3.2   | 2.4   | 2.1   | 2.1   | 1.9   |
| SR        | 1.17                                 | 1.20 | 1.12  | 1.12  | 1.10  | 1.05  | 1.37  | 1.36  | 1.41  | 19.9                                       | 20.1 | 18.2 | 17.2 | 16.3  | 14.8  | 18.4  | 18.0  | 16.5  |
| StbR      | 0.36                                 | 0.39 | 0.35  | 0.31  | 0.29  | 0.25  | 0.21  | 0.16  | 0.18  | 6.9                                        | 7.4  | 6.4  | 5.4  | 4.8   | 4.0   | 3.3   | 2.4   | 2.6   |

Table B-8 Delta (Project – Existing) D.O. Percentiles for Zones' Averages: Plan 6a, 4 ft deepening, and mitigation D.O. injections

| Zone Name | Project - Baseline Difference (mg/l) |      |       |       |       |       |       |       |       | Project - Baseline Relative Difference (%) |      |      |      |       |       |       |       |       |
|-----------|--------------------------------------|------|-------|-------|-------|-------|-------|-------|-------|--------------------------------------------|------|------|------|-------|-------|-------|-------|-------|
|           | 1%                                   | 5%   | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   | 1%                                         | 5%   | 10%  | 25%  | 50%   | 75%   | 90%   | 95%   | 99%   |
| FR1       | 0.07                                 | 0.06 | 0.05  | 0.09  | 0.07  | 0.04  | 0.04  | 0.02  | -0.02 | 1.6                                        | 1.4  | 1.1  | 2.1  | 1.6   | 0.9   | 0.7   | 0.4   | -0.4  |
| FR2       | 0.20                                 | 0.17 | 0.14  | 0.18  | 0.15  | 0.18  | 0.14  | 0.14  | 0.13  | 4.9                                        | 4.1  | 3.3  | 4.1  | 3.2   | 3.7   | 2.8   | 2.8   | 2.7   |
| FR3       | 0.15                                 | 0.18 | 0.18  | 0.23  | 0.20  | 0.16  | 0.16  | 0.10  | 0.04  | 3.7                                        | 4.4  | 4.4  | 5.2  | 4.5   | 3.5   | 3.2   | 1.9   | 0.7   |
| FR4       | 0.21                                 | 0.22 | 0.27  | 0.27  | 0.26  | 0.21  | 0.09  | 0.03  | 0.03  | 5.0                                        | 5.4  | 6.3  | 6.1  | 5.7   | 4.2   | 1.7   | -0.5  | 0.6   |
| FR5       | 0.24                                 | 0.25 | 0.28  | 0.26  | 0.24  | 0.09  | -0.04 | 0.04  | 0.05  | 5.7                                        | 5.9  | 6.5  | 5.7  | 5.1   | 1.8   | -0.6  | 0.6   | 0.8   |
| FR6       | 0.23                                 | 0.23 | 0.21  | 0.19  | 0.09  | -0.05 | -0.06 | 0.09  | 0.13  | 5.5                                        | 5.3  | 4.6  | 3.9  | 1.7   | -0.3  | -1.1  | 1.4   | 2.1   |
| FR7       | 0.15                                 | 0.10 | 0.09  | 0.02  | -0.05 | 0.11  | 0.13  | 0.08  | 0.05  | 3.3                                        | 2.1  | 1.9  | 0.4  | -0.8  | 1.7   | 2.0   | 1.2   | 0.8   |
| FR8       | 0.11                                 | 0.01 | 0.03  | -0.02 | 0.09  | 0.19  | 0.18  | 0.15  | 0.17  | 2.2                                        | 0.1  | 0.5  | -0.4 | 1.4   | 2.9   | 2.6   | 2.1   | 2.3   |
| FR9       | 0.01                                 | 0.06 | 0.07  | 0.14  | 0.22  | 0.23  | 0.23  | 0.31  | 0.34  | 0.1                                        | 1.1  | 1.2  | 2.2  | 3.3   | 3.4   | 3.3   | 4.2   | 4.6   |
| FR10      | 0.48                                 | 0.48 | 0.44  | 0.46  | 0.45  | 0.45  | 0.54  | 0.57  | 0.66  | 8.4                                        | 8.0  | 7.1  | 7.2  | 6.8   | 6.5   | 7.4   | 7.8   | 8.9   |
| FR11      | 0.55                                 | 0.51 | 0.48  | 0.47  | 0.43  | 0.39  | 0.47  | 0.51  | 0.55  | 9.7                                        | 8.7  | 8.3  | 7.4  | 6.5   | 5.7   | 6.5   | 7.0   | 7.4   |
| MR1       | 0.18                                 | 0.23 | 0.24  | 0.27  | 0.27  | 0.19  | 0.17  | 0.18  | 0.18  | 3.8                                        | 4.8  | 4.8  | 5.1  | 4.8   | 3.2   | 2.8   | 2.9   | 2.8   |
| MR2       | 0.50                                 | 0.53 | 0.48  | 0.45  | 0.39  | 0.27  | 0.20  | 0.19  | 0.22  | 10.7                                       | 11.0 | 9.6  | 8.6  | 7.2   | 4.6   | 3.4   | 3.1   | 3.5   |
| MR3       | 0.85                                 | 0.83 | 0.79  | 0.77  | 0.68  | 0.49  | 0.37  | 0.35  | 0.39  | 18.9                                       | 17.6 | 16.2 | 15.1 | 12.5  | 8.4   | 6.0   | 5.6   | 6.2   |
| MR4       | 0.80                                 | 0.80 | 0.80  | 0.83  | 0.82  | 0.87  | 0.96  | 1.08  | 1.08  | 16.1                                       | 15.5 | 15.3 | 15.4 | 14.5  | 14.8  | 15.8  | 17.8  | 17.3  |
| MR5       | 1.07                                 | 1.12 | 1.13  | 1.06  | 0.93  | 0.74  | 0.79  | 0.73  | 0.72  | 25.6                                       | 24.9 | 24.1 | 21.0 | 16.1  | 11.4  | 11.6  | 10.3  | 9.9   |
| MR6       | 0.10                                 | 0.00 | -0.11 | -0.22 | -0.69 | -0.92 | -1.24 | -1.26 | -1.34 | 2.5                                        | 0.0  | -2.4 | -4.2 | -11.7 | -14.2 | -17.8 | -17.7 | -18.2 |
| LBR1      | 0.95                                 | 0.93 | 0.97  | 0.96  | 0.98  | 1.03  | 1.16  | 1.18  | 1.19  | 20.0                                       | 18.6 | 19.0 | 18.1 | 17.8  | 18.0  | 19.8  | 19.8  | 19.7  |
| LBR2      | 1.11                                 | 1.07 | 1.07  | 1.11  | 1.10  | 1.14  | 1.28  | 1.28  | 1.35  | 24.9                                       | 23.4 | 23.1 | 23.1 | 21.9  | 21.8  | 24.2  | 23.8  | 24.6  |
| LBR3      | 0.51                                 | 0.62 | 0.65  | 0.67  | 0.69  | 0.83  | 0.94  | 1.00  | 1.12  | 12.4                                       | 14.7 | 15.2 | 14.8 | 14.7  | 17.0  | 19.1  | 19.9  | 22.3  |
| BR1       | 0.27                                 | 0.37 | 0.32  | 0.38  | 0.43  | 0.42  | 0.40  | 0.37  | 0.38  | 7.2                                        | 9.6  | 8.0  | 9.2  | 10.0  | 9.3   | 8.5   | 7.8   | 7.8   |
| BR2       | 0.28                                 | 0.30 | 0.32  | 0.30  | 0.31  | 0.45  | 0.49  | 0.34  | 0.33  | 7.7                                        | 8.2  | 8.5  | 7.9  | 7.8   | 10.7  | 11.3  | 7.4   | 7.0   |
| BR3       | 0.06                                 | 0.13 | 0.15  | 0.18  | 0.15  | 0.16  | 0.26  | 0.34  | 0.35  | 1.5                                        | 3.3  | 3.8  | 4.6  | 3.7   | 3.8   | 5.9   | 7.8   | 7.9   |
| SCh1      | 0.09                                 | 0.12 | 0.09  | 0.12  | 0.11  | 0.06  | 0.04  | 0.04  | 0.03  | 2.1                                        | 2.8  | 2.2  | 2.8  | 2.5   | 1.3   | 0.9   | 0.8   | 0.6   |
| SCh2      | 0.11                                 | 0.14 | 0.11  | 0.12  | 0.15  | 0.12  | 0.10  | 0.11  | 0.09  | 2.5                                        | 3.1  | 2.5  | 2.6  | 3.1   | 2.5   | 2.0   | 2.2   | 1.7   |
| SR        | 1.06                                 | 1.09 | 1.02  | 1.03  | 1.00  | 0.95  | 1.24  | 1.23  | 1.28  | 18.1                                       | 18.3 | 16.6 | 15.7 | 14.8  | 13.4  | 16.7  | 16.3  | 16.8  |
| StbR      | 0.36                                 | 0.37 | 0.31  | 0.29  | 0.28  | 0.24  | 0.20  | 0.15  | 0.14  | 7.0                                        | 6.9  | 5.7  | 5.1  | 4.6   | 3.8   | 3.1   | 2.3   | 2.1   |

Table B-9 Delta (Project – Existing) D.O. Percentiles for Zones' Averages: Plan 6a, 3 ft deepening, and mitigation D.O. injections

| Zone Name | Project - Baseline Difference (mg/l) |      |       |       |       |       |       |       |       | Project - Baseline Relative Difference (%) |      |      |      |       |       |       |       |       |
|-----------|--------------------------------------|------|-------|-------|-------|-------|-------|-------|-------|--------------------------------------------|------|------|------|-------|-------|-------|-------|-------|
|           | 1%                                   | 5%   | 10%   | 25%   | 50%   | 75%   | 90%   | 95%   | 99%   | 1%                                         | 5%   | 10%  | 25%  | 50%   | 75%   | 90%   | 95%   | 99%   |
| FR1       | 0.08                                 | 0.06 | 0.07  | 0.09  | 0.07  | 0.05  | 0.03  | 0.02  | -0.02 | 1.7                                        | 1.4  | 1.5  | 2.0  | 1.6   | 1.0   | 0.7   | 0.3   | -0.6  |
| FR2       | 0.19                                 | 0.17 | 0.14  | 0.18  | 0.15  | 0.18  | 0.14  | 0.15  | 0.14  | 4.7                                        | 4.1  | 3.3  | 4.2  | 3.2   | 3.9   | 2.9   | 3.1   | 2.9   |
| FR3       | 0.14                                 | 0.18 | 0.18  | 0.23  | 0.20  | 0.17  | 0.18  | 0.15  | 0.10  | 3.4                                        | 4.3  | 4.3  | 5.2  | 4.5   | 3.6   | 3.7   | 2.9   | 1.9   |
| FR4       | 0.19                                 | 0.21 | 0.22  | 0.24  | 0.22  | 0.19  | 0.11  | 0.09  | 0.08  | 4.6                                        | 5.0  | 5.3  | 5.5  | 4.9   | 3.9   | 2.1   | -1.6  | 1.5   |
| FR5       | 0.21                                 | 0.20 | 0.24  | 0.23  | 0.19  | 0.10  | 0.00  | 0.11  | 0.11  | 5.0                                        | 4.7  | 5.6  | 5.1  | 4.1   | 2.0   | 0.0   | 1.8   | 1.8   |
| FR6       | 0.17                                 | 0.18 | 0.17  | 0.15  | 0.08  | 0.00  | 0.03  | 0.18  | 0.19  | 4.0                                        | 4.1  | 3.8  | 3.2  | 1.5   | 0.0   | 0.5   | 2.6   | 3.0   |
| FR7       | 0.13                                 | 0.08 | 0.08  | 0.03  | 0.02  | 0.17  | 0.15  | 0.15  | 0.09  | 2.8                                        | 1.7  | 1.6  | 0.6  | 0.4   | 2.6   | 2.2   | 2.2   | 1.3   |
| FR8       | 0.11                                 | 0.03 | 0.05  | 0.01  | 0.14  | 0.21  | 0.20  | 0.13  | 0.25  | 2.1                                        | 0.5  | 1.0  | 0.2  | 2.3   | 3.2   | 2.9   | 1.8   | 3.5   |
| FR9       | 0.05                                 | 0.12 | 0.13  | 0.18  | 0.24  | 0.25  | 0.27  | 0.32  | 0.37  | 0.9                                        | 1.9  | 2.2  | 2.8  | 3.7   | 3.7   | 3.8   | 4.4   | 4.9   |
| FR10      | 0.49                                 | 0.47 | 0.44  | 0.46  | 0.46  | 0.48  | 0.53  | 0.57  | 0.65  | 8.4                                        | 7.8  | 7.1  | 7.2  | 6.6   | 6.5   | 7.3   | 7.7   | 8.8   |
| FR11      | 0.55                                 | 0.51 | 0.50  | 0.47  | 0.43  | 0.35  | 0.47  | 0.51  | 0.55  | 9.7                                        | 8.7  | 8.3  | 7.4  | 6.5   | 5.6   | 6.5   | 7.0   | 7.4   |
| MR1       | 0.16                                 | 0.22 | 0.23  | 0.27  | 0.29  | 0.23  | 0.20  | 0.22  | 0.18  | 3.3                                        | 4.4  | 4.5  | 5.2  | 5.2   | 3.8   | 3.4   | 3.6   | 2.9   |
| MR2       | 0.50                                 | 0.57 | 0.50  | 0.48  | 0.42  | 0.30  | 0.24  | 0.21  | 0.26  | 10.7                                       | 11.9 | 10.1 | 9.2  | 7.6   | 5.1   | 4.0   | 3.4   | 4.1   |
| MR3       | 0.88                                 | 0.85 | 0.80  | 0.79  | 0.69  | 0.50  | 0.38  | 0.36  | 0.38  | 19.3                                       | 17.9 | 16.5 | 15.4 | 12.8  | 8.6   | 6.2   | 5.8   | 6.0   |
| MR4       | 0.80                                 | 0.79 | 0.80  | 0.82  | 0.81  | 0.87  | 0.95  | 1.06  | 1.07  | 16.2                                       | 15.3 | 15.2 | 15.1 | 14.4  | 14.8  | 15.6  | 17.3  | 17.2  |
| MR5       | 1.08                                 | 1.11 | 1.13  | 1.08  | 0.93  | 0.74  | 0.79  | 0.73  | 0.72  | 25.6                                       | 24.8 | 24.1 | 21.1 | 16.1  | 11.5  | 11.6  | 10.2  | 9.8   |
| MR6       | 0.11                                 | 0.01 | -0.11 | -0.22 | -0.70 | -0.92 | -1.24 | -1.26 | -1.33 | 2.8                                        | 0.2  | -2.3 | -4.4 | -11.7 | -14.2 | -17.8 | -17.7 | -18.1 |
| LBR1      | 0.95                                 | 0.93 | 0.97  | 0.97  | 0.97  | 1.02  | 1.16  | 1.18  | 1.20  | 19.8                                       | 18.6 | 19.1 | 18.2 | 17.7  | 17.8  | 19.7  | 19.6  | 18.7  |
| LBR2      | 1.11                                 | 1.07 | 1.07  | 1.11  | 1.10  | 1.15  | 1.28  | 1.27  | 1.30  | 24.9                                       | 23.4 | 23.0 | 22.9 | 21.8  | 22.1  | 24.1  | 23.6  | 23.6  |
| LBR3      | 0.52                                 | 0.63 | 0.66  | 0.67  | 0.70  | 0.82  | 0.94  | 1.00  | 1.13  | 12.6                                       | 14.9 | 15.4 | 15.0 | 14.8  | 17.0  | 19.0  | 20.1  | 22.4  |
| BR1       | 0.25                                 | 0.34 | 0.28  | 0.35  | 0.41  | 0.42  | 0.39  | 0.37  | 0.37  | 6.6                                        | 8.9  | 7.1  | 8.6  | 9.5   | 9.2   | 8.4   | 7.7   | 7.6   |
| BR2       | 0.25                                 | 0.27 | 0.29  | 0.28  | 0.28  | 0.42  | 0.47  | 0.32  | 0.31  | 6.8                                        | 7.3  | 7.7  | 7.3  | 7.0   | 9.9   | 10.7  | 7.0   | 6.6   |
| BR3       | 0.02                                 | 0.11 | 0.13  | 0.16  | 0.15  | 0.15  | 0.26  | 0.35  | 0.35  | 0.8                                        | 2.9  | 3.3  | 4.2  | 3.6   | 3.7   | 6.0   | 8.1   | 8.0   |
| SCh1      | 0.05                                 | 0.08 | 0.08  | 0.11  | 0.10  | 0.05  | 0.02  | 0.02  | 0.02  | -1.2                                       | -2.0 | -1.9 | -2.5 | -2.2  | -1.1  | -0.5  | -0.5  | -0.5  |
| SCh2      | 0.11                                 | 0.13 | 0.12  | 0.13  | 0.15  | 0.12  | 0.11  | 0.10  | 0.09  | 2.5                                        | 3.0  | 2.6  | 2.8  | 3.2   | 2.4   | 2.2   | 2.0   | 1.8   |
| SR        | 1.06                                 | 1.09 | 1.02  | 1.03  | 1.00  | 0.95  | 1.24  | 1.23  | 1.28  | 18.1                                       | 18.3 | 16.6 | 15.7 | 14.8  | 13.4  | 16.7  | 16.3  | 16.8  |
| StbR      | 0.38                                 | 0.38 | 0.34  | 0.30  | 0.31  | 0.29  | 0.23  | 0.21  | 0.20  | 7.2                                        | 7.2  | 6.2  | 5.2  | 5.1   | 4.6   | 3.6   | 3.1   | 2.9   |

Table B-10 Delta (Project – Existing) D.O. Percentiles for Zones' Averages: Plan 6b, 2 ft deepening, and mitigation D.O. injections

| Zone Name | Project - Baseline Difference (mg/l) |       |       |      |      |      |      |      |       | Project - Baseline Relative Difference (%) |      |      |      |      |      |      |      |      |
|-----------|--------------------------------------|-------|-------|------|------|------|------|------|-------|--------------------------------------------|------|------|------|------|------|------|------|------|
|           | 1%                                   | 5%    | 10%   | 25%  | 50%  | 75%  | 90%  | 95%  | 99%   | 1%                                         | 5%   | 10%  | 25%  | 50%  | 75%  | 90%  | 95%  | 99%  |
| FR1       | 0.07                                 | 0.06  | 0.05  | 0.07 | 0.08 | 0.07 | 0.05 | 0.03 | -0.01 | 1.7                                        | 1.3  | 1.2  | 1.6  | 1.7  | 1.4  | 1.0  | 0.5  | -0.2 |
| FR2       | 0.21                                 | 0.18  | 0.15  | 0.20 | 0.17 | 0.20 | 0.18 | 0.21 | 0.22  | 5.0                                        | 4.2  | 3.6  | 4.4  | 3.7  | 4.3  | 3.7  | 4.3  | 4.4  |
| FR3       | 0.15                                 | 0.18  | 0.19  | 0.24 | 0.23 | 0.21 | 0.24 | 0.25 | 0.24  | 3.7                                        | 4.3  | 4.5  | 5.5  | 5.2  | 4.4  | 5.0  | 4.9  | 4.5  |
| FR4       | 0.20                                 | 0.22  | 0.24  | 0.26 | 0.26 | 0.25 | 0.23 | 0.23 | 0.20  | 4.8                                        | 5.3  | 5.8  | 6.0  | 5.7  | 5.2  | 4.3  | 4.1  | 3.5  |
| FR5       | 0.23                                 | 0.23  | 0.26  | 0.26 | 0.23 | 0.19 | 0.14 | 0.21 | 0.21  | 5.4                                        | 5.5  | 5.9  | 5.7  | 4.9  | 3.6  | 2.4  | 3.5  | 3.5  |
| FR6       | 0.21                                 | 0.20  | 0.21  | 0.20 | 0.15 | 0.10 | 0.17 | 0.23 | 0.25  | 4.9                                        | 4.7  | 4.8  | 4.3  | 2.9  | 1.7  | 2.8  | 3.7  | 4.0  |
| FR7       | 0.18                                 | 0.14  | 0.14  | 0.11 | 0.13 | 0.22 | 0.20 | 0.17 | 0.14  | 4.0                                        | 3.0  | 2.7  | 2.0  | 2.1  | 3.6  | 3.0  | 2.5  | 2.0  |
| FR8       | 0.19                                 | 0.09  | 0.14  | 0.11 | 0.23 | 0.25 | 0.24 | 0.19 | 0.27  | 3.7                                        | 1.7  | 2.5  | 1.9  | 3.7  | 3.8  | 3.5  | 2.7  | 3.7  |
| FR9       | 0.14                                 | 0.19  | 0.25  | 0.25 | 0.30 | 0.30 | 0.31 | 0.34 | 0.38  | 2.4                                        | 3.3  | 4.0  | 3.9  | 4.5  | 4.3  | 4.3  | 4.6  | 5.1  |
| FR10      | 0.50                                 | 0.48  | 0.45  | 0.48 | 0.46 | 0.48 | 0.54 | 0.58 | 0.67  | 8.4                                        | 8.0  | 7.2  | 7.4  | 6.9  | 6.7  | 7.6  | 7.8  | 9.0  |
| FR11      | 0.55                                 | 0.51  | 0.49  | 0.47 | 0.43 | 0.39 | 0.47 | 0.52 | 0.55  | 9.6                                        | 8.7  | 8.2  | 7.4  | 6.4  | 5.7  | 6.5  | 7.1  | 7.4  |
| MR1       | 0.21                                 | 0.27  | 0.27  | 0.32 | 0.29 | 0.26 | 0.25 | 0.25 | 0.22  | 4.4                                        | 5.6  | 5.3  | 5.0  | 5.2  | 4.4  | 4.1  | 4.1  | 3.5  |
| MR2       | 0.56                                 | 0.56  | 0.47  | 0.45 | 0.42 | 0.28 | 0.24 | 0.22 | 0.26  | 12.1                                       | 11.7 | 9.5  | 8.7  | 7.6  | 4.8  | 3.9  | 3.6  | 4.2  |
| MR3       | 0.81                                 | 0.73  | 0.74  | 0.70 | 0.63 | 0.45 | 0.31 | 0.30 | 0.25  | 17.7                                       | 15.6 | 15.3 | 13.7 | 11.5 | 7.6  | 5.0  | 4.8  | 3.9  |
| MR4       | 0.72                                 | 0.65  | 0.69  | 0.69 | 0.69 | 0.71 | 0.79 | 0.87 | 0.94  | 14.5                                       | 12.5 | 13.1 | 12.7 | 12.1 | 12.1 | 12.9 | 14.3 | 15.0 |
| MR5       | 0.54                                 | 0.66  | 0.60  | 0.64 | 0.79 | 0.72 | 0.77 | 0.73 | 0.70  | 12.9                                       | 12.6 | 12.9 | 12.8 | 13.6 | 11.1 | 11.3 | 10.2 | 9.6  |
| MR6       | 2.00                                 | 1.85  | 1.69  | 1.54 | 0.90 | 0.51 | 0.27 | 0.20 | 0.07  | 48.1                                       | 41.1 | 35.6 | 30.3 | 15.3 | 7.8  | 3.9  | 2.9  | 0.9  |
| LBR1      | 0.75                                 | 0.74  | 0.75  | 0.75 | 0.73 | 0.73 | 0.88 | 0.87 | 0.86  | 15.6                                       | 14.8 | 14.8 | 14.2 | 13.3 | 12.8 | 15.0 | 14.6 | 14.2 |
| LBR2      | 0.85                                 | 0.81  | 0.82  | 0.82 | 0.80 | 0.83 | 0.94 | 0.98 | 0.96  | 19.1                                       | 17.8 | 17.7 | 17.1 | 15.8 | 15.9 | 17.7 | 18.1 | 17.6 |
| LBR3      | -0.03                                | 0.01  | 0.07  | 0.13 | 0.24 | 0.42 | 0.55 | 0.60 | 0.72  | -2.1                                       | 0.2  | 1.5  | 2.8  | 5.0  | 8.6  | 11.1 | 12.0 | 14.3 |
| BR1       | 0.00                                 | 0.63  | 0.57  | 0.52 | 0.49 | 0.50 | 0.46 | 0.44 | 0.43  | 16.2                                       | 16.6 | 14.4 | 12.5 | 11.5 | 11.0 | 9.9  | 9.3  | 8.9  |
| BR2       | 0.88                                 | 0.72  | 0.74  | 0.76 | 0.74 | 0.76 | 0.71 | 0.56 | 0.53  | 18.9                                       | 19.5 | 19.8 | 19.3 | 18.4 | 18.1 | 16.2 | 12.2 | 11.3 |
| BR3       | -0.11                                | -0.05 | -0.02 | 0.10 | 0.08 | 0.10 | 0.13 | 0.17 | 0.21  | -2.0                                       | -1.3 | -0.5 | 2.4  | 2.1  | 2.3  | 2.9  | 4.0  | 4.6  |
| SCh1      | 0.09                                 | 0.10  | 0.09  | 0.11 | 0.10 | 0.05 | 0.04 | 0.04 | 0.04  | 2.2                                        | 2.5  | 2.3  | 2.6  | 2.3  | 1.2  | 0.9  | 0.9  | 0.8  |
| SCh2      | 0.13                                 | 0.15  | 0.13  | 0.14 | 0.16 | 0.13 | 0.12 | 0.12 | 0.11  | 2.9                                        | 3.3  | 2.8  | 2.9  | 3.4  | 2.7  | 2.5  | 2.4  | 2.2  |
| SR        | 1.06                                 | 1.09  | 1.02  | 1.03 | 1.00 | 0.95 | 1.25 | 1.23 | 1.28  | 18.1                                       | 18.3 | 16.6 | 15.7 | 14.8 | 13.4 | 16.7 | 16.3 | 16.8 |
| StbR      | 0.40                                 | 0.41  | 0.38  | 0.34 | 0.34 | 0.31 | 0.28 | 0.24 | 0.23  | 7.7                                        | 7.8  | 6.9  | 6.0  | 5.5  | 4.9  | 4.4  | 3.6  | 3.4  |

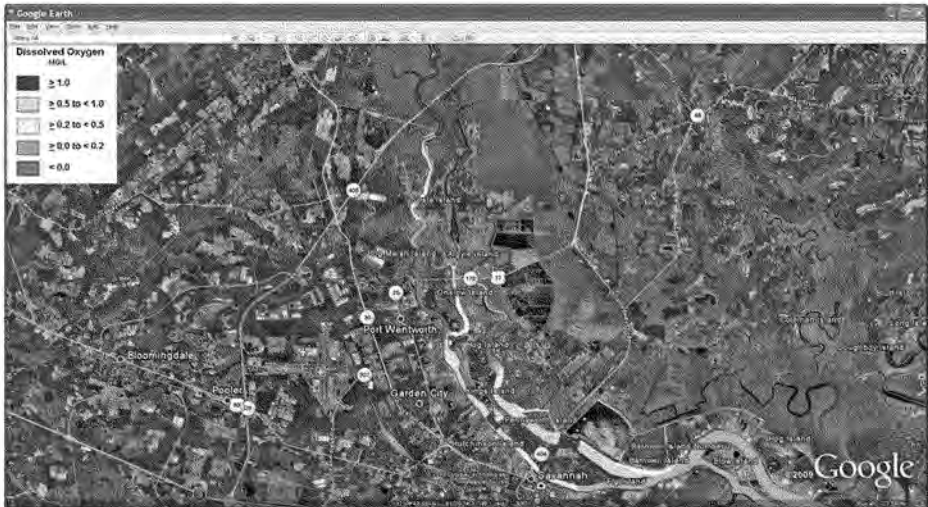


Figure B-1 Delta D.O. (50<sup>th</sup> percentile): Mitigation plan 6a-6ft and D.O. discharge

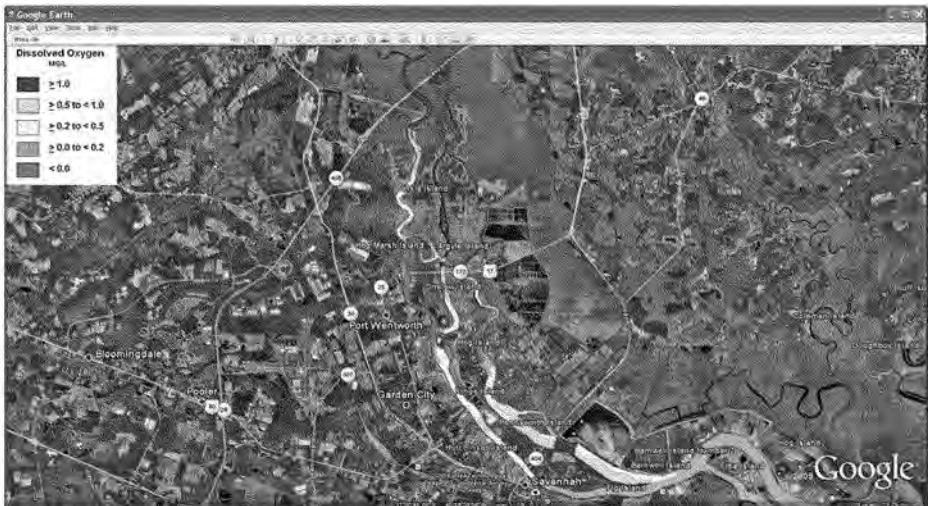


Figure B-2 Delta D.O. (50<sup>th</sup> percentile): Mitigation plan 6a-5ft and D.O. discharge



Figure B-3 Delta D.O. (50<sup>th</sup> percentile): Mitigation plan 6a-4ft and D.O. discharge



Figure B-4 Delta D.O. (50<sup>th</sup> percentile): Mitigation plan 6a-3ft and D.O. discharge





Figure B-5 Delta D.O. (50<sup>th</sup> percentile): Mitigation plan 6b-2ft and D.O. discharge

**APPENDIX C****DISSOLVED OXYGEN MITIGATION RESULTS FOR OXYGEN  
IMPROVEMENT SYSTEMS LOCATED NEAR INTERNATIONAL PAPER  
AND GEORGIA PACIFIC****TABLES**





Table C-1 Mitigation success for facilities located near IP and GP: 1BL criteria, 5<sup>th</sup> percentile

| Vertical Layer | DEPTH ALTERNATIVE |         |         |         |         |
|----------------|-------------------|---------|---------|---------|---------|
|                | 44-foot           | 45-foot | 46-foot | 47-foot | 48-foot |
| Surface        | 98.9              | 99.8    | 99.8    | 99.8    | 99.8    |
| Mid-Depth      | 93.3              | 98.4    | 98      | 98.1    | 98.2    |
| Bottom         | 97.2              | 97.1    | 97.5    | 97.3    | 97      |
| Water          |                   |         |         |         |         |
| Column         | 97.6              | 99.9    | 99.9    | 99.9    | 99.9    |

Table C-2 Mitigation success for facilities located near IP and GP: 1BL criteria, 10<sup>th</sup> percentile

| Vertical Layer | DEPTH ALTERNATIVE |         |         |         |         |
|----------------|-------------------|---------|---------|---------|---------|
|                | 44-foot           | 45-foot | 46-foot | 47-foot | 48-foot |
| Surface        | 99.5              | 99.7    | 99.7    | 99.7    | 99.7    |
| Mid-Depth      | 93.5              | 98.5    | 97.9    | 98      | 98.1    |
| Bottom         | 97.4              | 98.1    | 97.3    | 97.3    | 98.6    |
| Water          |                   |         |         |         |         |
| Column         | 97.5              | 99.9    | 99.9    | 99.9    | 99.9    |

Table C-3 Mitigation success for facilities located near IP and GP: 1BL criteria, 25<sup>th</sup> percentile

| Vertical Layer | DEPTH ALTERNATIVE |         |         |         |         |
|----------------|-------------------|---------|---------|---------|---------|
|                | 44-foot           | 45-foot | 46-foot | 47-foot | 48-foot |
| Surface        | 99.9              | 99.8    | 99.9    | 99.9    | 99.9    |
| Mid-Depth      | 94.5              | 98.7    | 98.4    | 98.3    | 98.5    |
| Bottom         | 97                | 98.5    | 97.3    | 98.1    | 98.4    |
| Water          |                   |         |         |         |         |
| Column         | 97.7              | 99.9    | 99.9    | 99.9    | 99.9    |

Table C-4 Mitigation success for facilities located near IP and GP: 1BL criteria, 50<sup>th</sup> percentile

| Vertical Layer | DEPTH ALTERNATIVE |         |         |         |         |
|----------------|-------------------|---------|---------|---------|---------|
|                | 44-foot           | 45-foot | 46-foot | 47-foot | 48-foot |
| Surface        | 99.7              | 99.7    | 99.6    | 99.6    | 99.6    |
| Mid-Depth      | 95.3              | 98.4    | 97.2    | 97.8    | 98      |
| Bottom         | 97.8              | 98.8    | 97.4    | 97.3    | 97      |
| Water          |                   |         |         |         |         |
| Column         | 98.2              | 99.9    | 99.9    | 99.9    | 99.9    |

Table C-5 Mitigation success for facilities located near IP and GP: 3BL criteria, 5<sup>th</sup> percentile

| Vertical Layer | DEPTH ALTERNATIVE |         |         |         |         |
|----------------|-------------------|---------|---------|---------|---------|
|                | 44-foot           | 45-foot | 46-foot | 47-foot | 48-foot |
| Surface        | 99.3              | 98      | 98      | 98.4    | 99.2    |
| Mid-Depth      | 94                | 94.5    | 94.5    | 96.2    | 95.1    |
| Bottom         | 96.9              | 93.9    | 92.3    | 95.1    | 96.4    |
| Water          |                   |         |         |         |         |
| Column         | 98                | 99.9    | 99.8    | 99.8    | 99.7    |

Table C-6 Mitigation success for facilities located near IP and GP: 3BL criteria, 10<sup>th</sup> percentile

| Vertical Layer | DEPTH ALTERNATIVE |         |         |         |         |
|----------------|-------------------|---------|---------|---------|---------|
|                | 44-foot           | 45-foot | 46-foot | 47-foot | 48-foot |
| Surface        | 99.5              | 98.1    | 98.3    | 98.6    | 99.1    |
| Mid-Depth      | 94.3              | 94.9    | 94.7    | 95.9    | 95.4    |
| Bottom         | 96.6              | 95.2    | 95      | 95.1    | 95.9    |
| Water          |                   |         |         |         |         |
| Column         | 98                | 99.9    | 99.8    | 99.8    | 99.9    |

Table C-7 Mitigation success for facilities located near IP and GP: 3BL criteria, 25<sup>th</sup> percentile

| Vertical Layer | DEPTH ALTERNATIVE |         |         |         |         |
|----------------|-------------------|---------|---------|---------|---------|
|                | 44-foot           | 45-foot | 46-foot | 47-foot | 48-foot |
| Surface        | 99.8              | 98.6    | 98.9    | 99      | 99.9    |
| Mid-Depth      | 94.9              | 95.9    | 95.9    | 96.6    | 96.5    |
| Bottom         | 95.8              | 94.7    | 94.3    | 94.3    | 94.7    |
| Water          |                   |         |         |         |         |
| Column         | 98.4              | 99.7    | 99.6    | 99.5    | 99.9    |

Table C-8 Mitigation success for facilities located near IP and GP: 3BL criteria, 50<sup>th</sup> percentile

| Vertical Layer | DEPTH ALTERNATIVE |         |         |         |         |
|----------------|-------------------|---------|---------|---------|---------|
|                | 44-foot           | 45-foot | 46-foot | 47-foot | 48-foot |
| Surface        | 99.7              | 99.2    | 98.9    | 99.1    | 99.6    |
| Mid-Depth      | 96.2              | 95.7    | 94.4    | 95      | 95.7    |
| Bottom         | 96.9              | 94.4    | 93.1    | 94      | 93.5    |
| Water          |                   |         |         |         |         |
| Column         | 98.8              | 99.3    | 98.8    | 98.9    | 98.9    |

**APPENDIX D****SAVANNAH ENHANCED MODEL (SHEP) POSTPROCESSOR**



The post-processor for Savannah enhanced hydrodynamic and water quality model (WAMS) is a stand-alone program that can read EFDC and WASP output files (BMD files) and generate required outputs in specific formats for impact analysis. The GUI of the current version of the postprocessor is presented on Figure D-1.

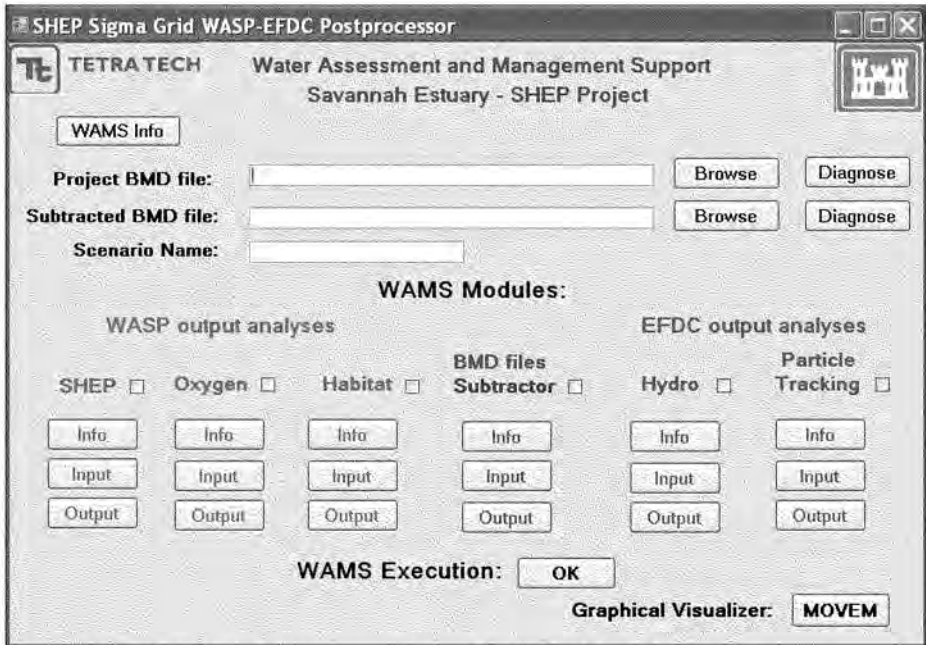


Figure D1 WASP-EFDC postprocessor for models developed for SHEP project

The module “Oxygenation” was developed for identification of parameters of dissolved oxygen improvement system and evaluation of effectiveness of SHEP mitigation measures.

The modified postprocessor outputs information for the following harbor’s spatial objects:

- Critical Cell – the cell with lowest D.O. concentrations during specified simulation period
- Critical Segment – an assemblage of cross section cells located at the critical cell’s j-coordinate
- Zone – an assemblage of cells that is limited by specified horizontal and vertical boundaries

The basic criteria for assessing the success of D.O. mitigation is the condition of meeting existing (pre-project) or higher values of D.O. concentrations for 97% of the estuarine waters at least. WAMS provides estimates of such waters volume for all user’s selected zones.

The postprocessor outputs the results of hydrodynamic and water quality simulations as a set of following files with tables:

1. File name: <Oxygen\Tables\><Scenario name><Mitigation success.CSV>. The tables contain the percentage of volume that meets 97% requirement for all cells of selected zones, all zones and the whole estuary for 1<sup>st</sup>, 5<sup>th</sup>, 10<sup>th</sup>, 25<sup>th</sup>, 50<sup>th</sup>, 75<sup>th</sup>, 95<sup>th</sup>, and 99<sup>th</sup> percentiles of D.O. concentrations.

2. File name: <Oxygen\Tables\><Scenario name><\_CriticCell\_DO\_%.CSV>. The table contains D.O. percentiles distribution for a cell with lowest D.O. concentrations inside each zone. The information allows purposefully focusing the mitigation measures on most critical parts of the zones.
3. File name: <Oxygen\Tables\><Scenario name><\_CriticCell\_Sal\_%.CSV>. The table contains salinity percentiles distribution for each zone's critical cell. It helps to identify salinity impact on formation of lowest D.O. concentrations inside each zone.

4. File name: <Oxygen\Tables\><Scenario name><\_C\_DO\_Viol.CSV>. The table contains percentage of simulation records with D.O. standards' violations for each cell of the computational grid during the simulation period:

$$A_i^k = \frac{100}{N_t} \sum_{t=1}^{N_t} \delta_{it}^k,$$

$$\delta_{it}^k = 1, \text{ if } C_{it} \geq S^k; \delta_{it}^k = 0, \text{ if } C_{it} < S^k$$

where  $A_i^k$  is a number of violations of the  $k$ -th D.O. standard  $S^k$  for  $i$ -th cell;  $C_{it}$  is the D.O. concentration in  $i$ -th cell for  $t$ -th record;  $N_t$  is the number of time records in BMD WASP output file

5. File name: <Oxygen\Tables\><Scenario name><\_C\_DO\_Viol\_Analys.CSV>. The table contains numbers of cells that correspond to deciles of the cumulative distribution function of numbers of violation of D.O. standards

$$G_j^k = \sum_{i=1}^{N_t} Z_{ij}^k, \quad j = 1, \dots, 10$$

$$\text{if } (j-1) * 10 < A_i^k \leq j * 10 \quad Z_{ij}^k = 1, \text{ otherwise } Z_{ij}^k = 0,$$

where  $G_j^k$  is the number of cells with  $k$ -th standard violation within a range of  $j$  and  $j-1$  deciles;  $N_t$  is the number of cells in the computational grid.

6. File name: <Oxygen\Tables\><Scenario name><\_C\_Viol\_WC\_Volume.CSV>. The table contains percentage of water volumes with violations of D.O. standards through the water column of each specified zone

$$B_m^k = \frac{\sum_{t=1}^{N_t} \sum_{n=1}^{N_v} \sum_{i=1}^{N_m} V_{im} \delta_{im}^k}{\sum_{t=1}^{N_t} \sum_{n=1}^{N_v} \sum_{i=1}^{N_m} V_{im}} \cdot 100\%$$

$$\delta_{im}^k = 1, \text{ if } C_{im} \geq S^k; \delta_{im}^k = 0, \text{ if } C_{im} < S^k$$

where  $N_v$  is the maximum number of vertical layers;  $N_m$  is the number of horizontal cells in a zone  $m$ ;  $V_{im}$  is the volume of a cell with coordinates  $(i, n)$  at time  $t$ .

7. File name: <Oxygen\Tables\><Scenario name><\_C\_Viol\_WL\_Volume.CSV>. The table contains percentage of water volume with violations of D.O. standards for each specified zone and selected vertical layers

$$B_m^k = \frac{\sum_{t=1}^{N_t} \sum_{n=N_b}^{N_e} \sum_{i=1}^{N_m} V_{in} \delta_{in}^k}{\sum_{t=1}^{N_t} \sum_{n=N_b}^{N_e} \sum_{i=1}^{N_m} V_{in}} \cdot 100$$

$$\delta_{in}^k = 1, \text{ if } C_{in} \geq S^k; \delta_{in}^k = 0, \text{ if } C_{in} < S^k$$

where  $N_b$  and  $N_e$  are the beginning and ending of vertical  $n$ -coordinates for zone  $m$ ;  $V_{ijn}$  is the volume of a cell with coordinates  $(i, j, n)$  at time  $t$ .

8. File name: <Oxygen\Tables\><Scenario name><CriticSeg\_DO\_A\_TS.CSV>. The table contains time series of 1-, 7-, and 30-day average D.O. for each critical segment's water column, and it's top and bottom halves
9. File name: <Oxygen\Tables\><Scenario name><CriticSeg\_Sal\_A\_TS.CSV>. The table contains time series of 1-, 7-, and 30-day average salinity for each critical segment's water column, and it's top and bottom halves
10. File name: <Oxygen\Tables\><Scenario name><\_Z\_DO\_%.CSV>. The table contains volume-weighted D.O. percentiles distributions for each zone and specified vertical layers
11. File name: <Oxygen\Tables\><Scenario name><\_Z\_Sal\_%.CSV>. The table contains volume-weighted salinity percentiles distributions for each zone and specified vertical layers
12. File name: <Oxygen\Tables\><Scenario name><\_Z\_DO\_Viol.CSV>. The table contains percentages ( $F_m$ ) of occurrences of D.O. standards violations by each zone's volume-weighted D.O.

$$R_m = \frac{\sum_{i=1}^{N_m} \sum_{n=N_b}^{N_e} V_{in} C_{in}}{\sum_{i=1}^{N_m} \sum_{n=N_b}^{N_e} V_{in}}$$

$$F_m = \frac{100\%}{N_t} \sum_{t=1}^{N_t} \delta_{in}^k$$

$$\delta_{in}^k = 1, \text{ if } R_m \geq S^k; \delta_{in}^k = 0, \text{ if } R_m < S^k$$

where  $R_m$  is the volume-weighted D.O. concentration for zone  $m$  and time record  $t$ .

13. File name: <Oxygen\Tables\><Scenario name><\_Z\_DO\_Mass.CSV>. The table contains D.O. deficit in reference to the current D.O. minimum standard St.4; average deficit over simulation period -  $D_{ms}$  as well as maximum instant D.O. deficit and time of this event for each specified zone

$$D_m = \frac{1}{N_t} \sum_{t=1}^{N_t} \sum_{n=N_b}^{N_e} \sum_{i=1}^{N_m} (S^k - C_{in})$$

The tables (items 10 – 13) contain information about each selected zone volume-weighted D.O. and salinity concentrations' averages and their correspondence to D.O. standards. The information allows estimating the contribution of each zone into the general pattern of D.O. regime of the estuary.

**APPENDIX E****ECO2 QUOTATION ON SPEECE CONE ON MARCH 17, 2010**





Eco2 quotation included below.



3/17/2010  
Savannah Harbor, Oxygen Injection  
ECO2 SuperOxygenation  
Preliminary design & budget estimate  
Steven Davie, Submitted by Eco Oxygen Technologies  
Oxygen supply by on site oxygen generation PSA

| Design Operating Conditions                                           |                  | units     |          |           |                    |
|-----------------------------------------------------------------------|------------------|-----------|----------|-----------|--------------------|
| Oxygen Supply                                                         |                  | lbs / day |          | 5,000     |                    |
| Electrical Unit Cost                                                  |                  | \$ / kwhr |          | \$0.06    |                    |
| Annual Usage                                                          |                  | days      |          | 180       |                    |
| ECO2 System Design and Capital Cost                                   |                  | units     | quantity | rate      | cost               |
| ECO2 cone with PLC oxygen flow control                                | 12 ft. Dia.      |           | 1        | \$748,474 | \$748,474          |
| Oxygen dissolution                                                    | 4,000 lbs / day  |           | 1        | 4,000     |                    |
| Side Stream Flow                                                      | 12,600 gpm       |           | 1        | 12,600    |                    |
| Sub total                                                             |                  |           |          |           | \$748,474          |
| Outsourced/3rd party Capital Cost                                     |                  | units     | quantity | rate      | cost               |
| Installation (including side stream pump)                             |                  |           | 1        | \$250,000 | \$250,000          |
| Oxygen Generator (PSA)                                                | 5,000 lbs / day  |           | 1        | \$170,000 | \$170,000          |
| Sub total                                                             |                  |           |          |           | \$420,000          |
| Annual Operating Cost                                                 |                  | units     | quantity | rate      | cost               |
| Electrical draw - Oxygen Generator                                    | 1,815 kwhr / day |           | 1        | \$0.06    | \$19,800           |
| Electrical draw - Side Stream Pump                                    | 75 hp            |           | 1        | \$0.06    | \$14,500           |
| O&M - Oxygen Generator & Side Stream Pump                             |                  |           |          | 20%       | \$6,800            |
| License fee - ECO2 process technology                                 | 4,000 lbs / day  |           | 1        | \$0.01    | \$7,200            |
| Sub total                                                             |                  |           |          |           | \$48,100           |
| <b>Total Capital Cost Estimate including Onsite Oxygen Generation</b> |                  |           |          |           | <b>\$1,168,474</b> |
| <b>Total Annual Operating Cost Estimate (180 days)</b>                |                  |           |          |           | <b>\$48,100</b>    |

**Notes:**

The cost estimate for installation, side stream pump and oxygen generation equipment need to be validated.

Cost estimates valid for 30 days and do not include taxes or shipping

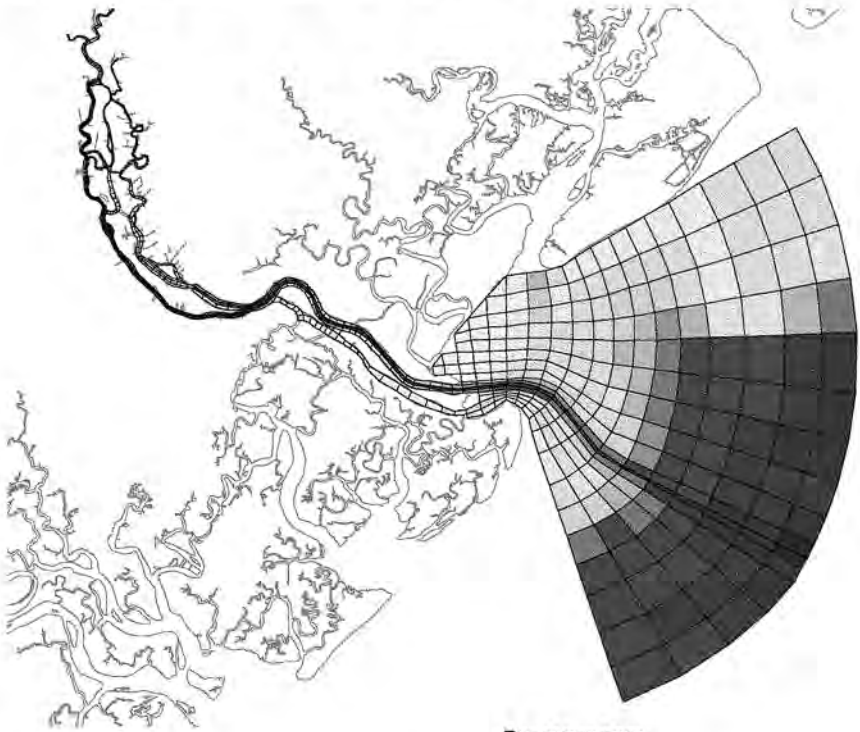
Cost estimates subject to verification of design data

Purchase subject to Terms & Conditions of Purchase Agreement and Process Technology License Agreement

Eco Oxygen Technologies  
3939 Priority Way South Drive, Suite 400, Indianapolis, IN 46240  
Tel: 317-706-6484 Fax: 317-816-0940 www.eco2tech.com

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# Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project

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**FINAL**  
January 30, 2006

---

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There was a significant amount of review and comments on the first draft of the modeling report. The first draft of the model was distributed in August 2004 as part of the TMDL development for the harbor. The enhanced model for the Savannah Harbor Expansion (SHE) project was delivered on the following dates: February 7, 2005 (Draft), March 31, 2005 (Draft-Final), May 20, 2005 (Final), and this final version on January 30, 2006 (Final-Final). A special thank you is owed to the SHE Model Review Team for their patience and diligence during the peer review of these reports and of the EFDC and WASP models. The members are as follows:

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- Jim Greenfield, US Environmental Protection Agency, Region 4
- William Bailey, US Army Corps of Engineers
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- Joe Hoke, US Army Corps of Engineers
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- Wade Cantrell, SCDHEC Water Quality Modeling Section
- Larry Turner, SCDHEC Water Quality Modeling Section
- Dr. Roy Burke, GA EPD Water Protection Branch
- Paul Lamarre, GA EPD Water Protection Branch
- Dr. Sung-Chan Kim, USACE-ERDC (CEERD-EP-W)
- Bob Scanlon, City of Savannah Environmental Affairs
- Larry Neal, MACTEC

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**Appendix A – Grid Convergence Test Results**

**Appendix B – 1999 Water Surface Elevation Comparisons**

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## 1.0 INTRODUCTION

Tetra Tech, Inc. (Tetra Tech) was contracted by the USACE Savannah District to enhance the existing three-dimensional hydrodynamic model (Environmental Fluid Dynamics Computer Code – EFDC) and the water quality model (Water Quality Analysis Simulation Program – WASP) application for the Savannah River and Harbor. Tetra Tech developed the EFDC hydrodynamic model and supported the United States Environmental Protection Agency (USEPA) Region 4 on the WASP model for developing the Total Maximum Daily Load (TMDL) for dissolved oxygen in the harbor.

The enhanced hydrodynamic and water quality models will be used to assess the environmental impacts of the Savannah Harbor Expansion (SHE) Project being led by the USACE Savannah District and the Georgia Ports Authority (GPA). The models are developed in consideration of the following efforts: (1) USACE Savannah Harbor Ecosystem Restoration Project, (2) finalization of the USEPA Region 4 Dissolved Oxygen TMDL, and (3) the states of Georgia and South Carolina issuing National Pollutant Discharge Elimination System (NPDES) permits. Therefore, federal and state agency review of model development and performance are critical to the success of using one model in Savannah Harbor. USEPA Region 4 is a Cooperating Agency for the SHE Project and has stated that these models will be adequate to evaluate water quality issues for the SHE Project.

USEPA Region 4 issued the draft dissolved oxygen TMDL on August 30, 2004 and the public notice/comment period ended on January 31, 2005. The TMDL models were run on a coarse grid in which the EFDC hydrodynamic and the WASP water quality models were applied. The coarse grid, now referred to as the TMDL grid, was documented in a report (Tetra Tech, 2004) and met the following objectives defined by USEPA:

- To represent accurately the key hydrodynamic processes of transport in the estuary,
- To utilize a model that is public domain and has been peer reviewed,
- To deliver the model to the federal agencies involved in the TMDL process,
- To run the model for multiple hydrologic periods and evaluate point and nonpoint sources, and
- To complete the effort in a timely manner in order to meet the project schedule.

The effort to develop an enhanced grid was initiated on September 29, 2004 to improve the representation of the estuary system and navigation channel from the TMDL grid. The enhanced grid is designed to allow evaluation of various scenarios such as deepening of the navigation channel and physical modifications to certain cuts and channels in the river and estuary. The major enhancements included developing a finer model grid, updating the bathymetric data used by the model, and an alternate approach for the model calculation of the river-marsh interactions. The same models, EFDC and WASP, were used on the TMDL grid and the enhanced grid.

This report includes both the hydrodynamic and water quality modeling results along with calibration and confirmation periods. The calibration of the models was performed to the summer of 1999 data, the period with the most comprehensive dataset. The confirmation of the model was performed to the summer of 1997 data and the USGS long-term data from January 1, 1997 through December 31, 2003.

The model applications described herein have been designed to meet the expectations of the model review team consisting of federal and state agencies. The model code, modeling results, in both time series and statistical formats, and a database, which contains all comparison data were also made available for peer review. Ultimately, the goals of the hydrodynamic and water quality models were to produce defensible, accurate, and logistical tools that the federal and state agencies could use to make management decisions for the Savannah Harbor and Savannah River Estuary.

### 1.1 Modeling Study Goals

The work presented in this report had two primary goals: (Task A) to modify and recalibrate the EFDC model and (Task B) to re-evaluate the calibration of the WASP water quality model, if needed, because of revisions to the EFDC hydrodynamic model. The objectives of Task A were to modify the EFDC model to improve the grid resolution, tidal-marsh interaction, and boundary conditions in response to issues raised during the SHE Project federal and state technical review of the initial calibration report on the EFDC portion of the TMDL grid. The objective of Task B was to re-evaluate the calibration of the WASP model for use in predicting dissolved oxygen in the harbor and use in future SHE Project alternatives. The USACE Savannah District along with the federal agencies believed that modifications to the TMDL grid of the EFDC and WASP models might enhance the TMDL Models' capabilities.

### 1.2 Coordination with the Water Quality Model Calibration

Selection of the hydrodynamic model was determined with the intent of linking the hydrodynamics (EFDC) to the water quality model (WASP). The parameters that the EFDC transfers to the WASP simulation are volume, depth, dispersion, salinity, temperature, and vertical mixing parameters. The linkage is critical for passing the information to a water quality model because the transport processes in the system determine the fate and transport of water quality constituents. For the new version of WASP (Version 7), the hydrodynamic linkage file has been further compressed in binary form so that file management of longer runs can be more efficient.

### 1.3 Report Contents

In addition to the report, there are two compact discs included in the back of the report. The compacts discs include the following:

- Modeling report in PDF format,
- EFDC model code,
- EFDC model input files,
- EFDC model output for calibration period (1999 summer),
- WASP setup with MOVEM post-processor,
- WASP project file,
- WASP model output for calibration period (1999 summer),
- Database files of calibration data, and
- GIS shape files.

The MOVEM post-processor allows technical reviewers to view the model results anywhere in the model domain and compare with measured data. MOVEM also has the capability to calculate statistics, including percentiles, and animate results in the model grid. For calculating statistics, MOVEM can focus on defined time periods to generate results. The datasets included on the compacts discs are for the summers of 1997 and 1999 as well as the United States Geological Survey (USGS) data for January 1, 1997 through December 31, 2003.

### 1.4 Project Location

The model application described in this report is located near Savannah, Georgia and is on the border between Georgia and South Carolina as shown in Figure 1-1. The enhanced model grid extends upstream on the Savannah River to river mile 61.0 near Clyo, Georgia at USGS Station 02198500. The downstream end of the model extends approximately 17 miles offshore from Oysterbed Island to cover the navigational channel of Savannah Harbor. This results in the model covering 78 miles of river, estuary, and ocean.

The modeling study area includes the Savannah River, the Front River, the Middle River, the Little Back River, the Back River, the South Channel, and the offshore portions in the Atlantic Ocean.

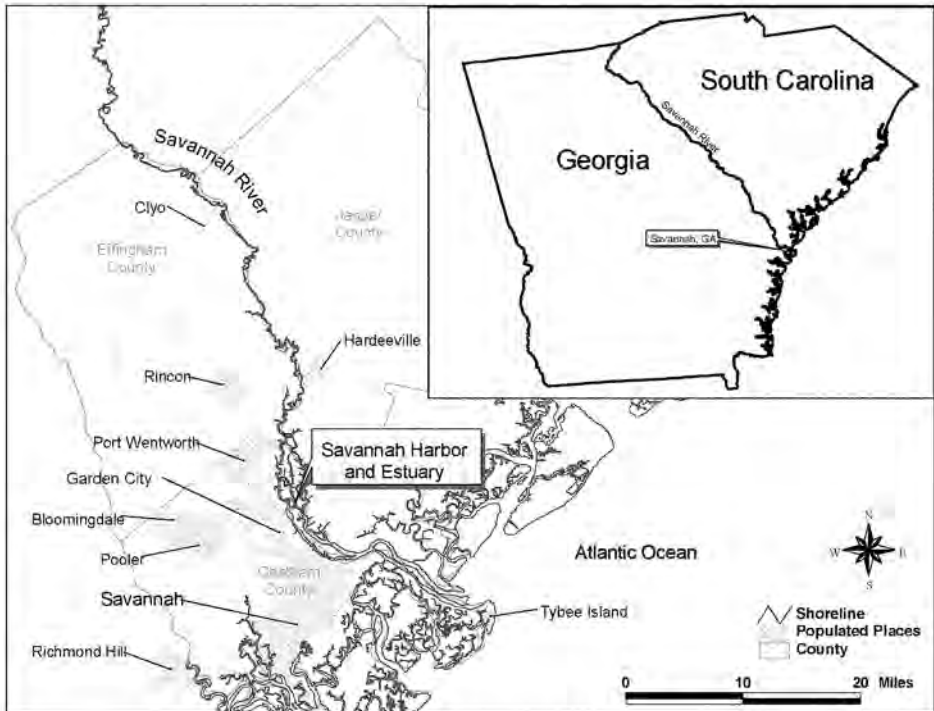


Figure 1-1 Project Location Map of the Savannah Harbor and Estuary

## 2.0 DATA ANALYSIS

The data used in the calibration and confirmation of the model were collected by the Georgia Ports Authority (GPA), the USGS, the Georgia Environmental Protection Division (GAEPD), the USACE, and the USEPA. An extensive amount of work has been completed to date on the data reporting and analysis by Applied Technology and Management, Inc. for GPA (ATM, 2000). MACTEC also has collected analyzed data in the harbor, specifically the longterm BOD (LTBOD) data, for the City of Savannah, Harbor Committee, and the USACE Savannah District. MACTEC performed the Wastewater Characterization Study in 1999 and also collected offshore samples in September 2003. These data will be discussed later in the Water Quality sections.

### 2.1 Location of Stations

The main stations used in the calibration and confirmation are from the GPA studies conducted in 1997 and 1999. Figure 2-1 shows the locations of the USGS stations and Figure 2-2 shows the locations of the 1997 and 1999 stations. Table 2-1 gives an overall list of the locations of these stations and the vertical placement in the water column which will be critical for the salinity calibration in the subsequent sections. The Clio flow gage is not shown in Figure 2-1.

Table 2-1 Description of USGS/GPA Stations in the Savannah River Estuary

| Station ID    | Description                          | River Mile | Parameters      | 1997 Location | 1999 Location | Lat     | Long     |
|---------------|--------------------------------------|------------|-----------------|---------------|---------------|---------|----------|
| GPA           |                                      |            |                 |               |               |         |          |
| FR-26         | Front River at Fort Pulaski          | 0.8        | S, T, WL, DO    |               | S & B         | 32.0363 | -80.9001 |
| FR-02         | Front River in the Entrance Channel  | 4.5        | S, T, WL, DO    | S & B         | S & B         | 32.0686 | -80.9528 |
| SC-03         | South Channel                        | 5.5        | S, T, WL, DO    | Bottom        | Bottom        | 32.0622 | -80.9662 |
| FR-04         | Front River near Fort Jackson        | 10.4       | S, T, WL, C, DO | S & B         | S & B         | 32.0890 | -81.0268 |
| FR-21         | Front River at USACE Depot           | 13.9       | S, T, WL, DO    |               | S & B         | 32.0794 | -81.0782 |
| BR-05         | Back River at Hwy 17                 | 14.5       | S, T, WL, DO    | Bottom        | Bottom        | 32.1000 | -81.0898 |
| FR-06         | Front River upstream of Talmadge Br  | 16.6       | S, T, WL, C, DO | S & B         | S & B         | 32.0964 | -81.1074 |
| FR-22         | Front River at K.L. Turning Basin    | 18.7       | S, T, WL, DO    |               | S & B         | 32.1286 | -81.1366 |
| BR-07         | Back River                           | 18.9       | S, T, WL, DO    | Bottom        | Surface       | 32.1464 | -81.1182 |
| FR-08         | Front River                          | 20.5       | S, T, WL, C, DO | S & B         | S & B         | 32.1500 | -81.1443 |
| LBR-15        | Little Back River at Houlihan Bridge | 20.9       | S, T, DO        | Mid-Depth     | Surface       | 32.1654 | -81.1296 |
| FR-09         | Front River at Houlihan Bridge       | 21.5       | S, T, WL, DO    | Bottom        | S & B         | 32.1653 | -81.1553 |
| MR-10         | Middle River at Houlihan Bridge      | 21.8       | S, T, DO        | Bottom        | Surface       | 32.1653 | -81.1384 |
| FR-11         | Front River                          | 24.7       | S, T, WL, DO    | Bottom        |               | 32.2008 | -81.1517 |
| FR-11R        | Front River, Revised 1999            | 23.4       | S, T, WL, DO    |               | Bottom        | 32.1866 | -81.1526 |
| MR-12         | Middle River                         | 24.4       | S, T, WL, DO    | Bottom        |               | 32.2012 | -81.1412 |
| MR-12R        | Middle River, Revised 1999           | 23.7       | S, T, DO        |               | Surface       | 32.1946 | -81.1384 |
| LBR-13        | Little Back River                    | 26.6       | S, T, WL, DO    | Bottom        |               | 32.2048 | -81.1262 |
| SR-14         | Savannah River                       | 27.7       | S, T, WL, DO    | Bottom        | Bottom        | 32.2347 | -81.1500 |
| USGS Stations |                                      |            |                 |               |               |         |          |
| 02198980      | Front River at Fort Pulaski          | 0.8        | WL              | Mid-Depth*    | Mid-Depth*    | 32.0341 | -80.9032 |
| 02198977      | Front River at Broad Street          | 14.6       | WL              | Mid-Depth*    | Mid-Depth*    | 32.0839 | -81.0958 |
| 02198920      | Front River at Houlihan Bridge       | 21.5       | S, WL           | Mid-Depth*    | Mid-Depth*    | 32.1680 | -81.1512 |
| 021989791     | Little Back River at USF&W Dock      | 22.1       | S               | Mid-Depth*    | Mid-Depth*    | 32.1708 | -81.1182 |
| 02198979      | Little Back River at Limehouse Cr    | 24.1       | WL              | Mid-Depth*    | Mid-Depth*    | 32.1849 | -81.1171 |
| 021989784     | Little Back River at Lucknow Canal   | 24.2       | S               | Mid-Depth*    | Mid-Depth*    | 32.1858 | -81.1179 |
| 02198840      | Savannah River at I-95 Bridge        | 27.7       | S, WL           | Mid-Depth*    | Mid-Depth*    | 32.2358 | -81.1512 |
| 02198500      | Savannah River near Clio, GA         | 61.0       | Q               | Mid-Depth*    | Mid-Depth*    | 32.5281 | -81.2689 |

NOTES:

S & B = Surface and Bottom

Parameters include S=Salinity, T=Temperature, WL=Water Level, C=Currents, Q=Flow, DO = Dissolved Oxygen

1. Location is describing vertical water column location.

2. Mid-Depth = 2.7 feet below Mean Low Water (MLW).

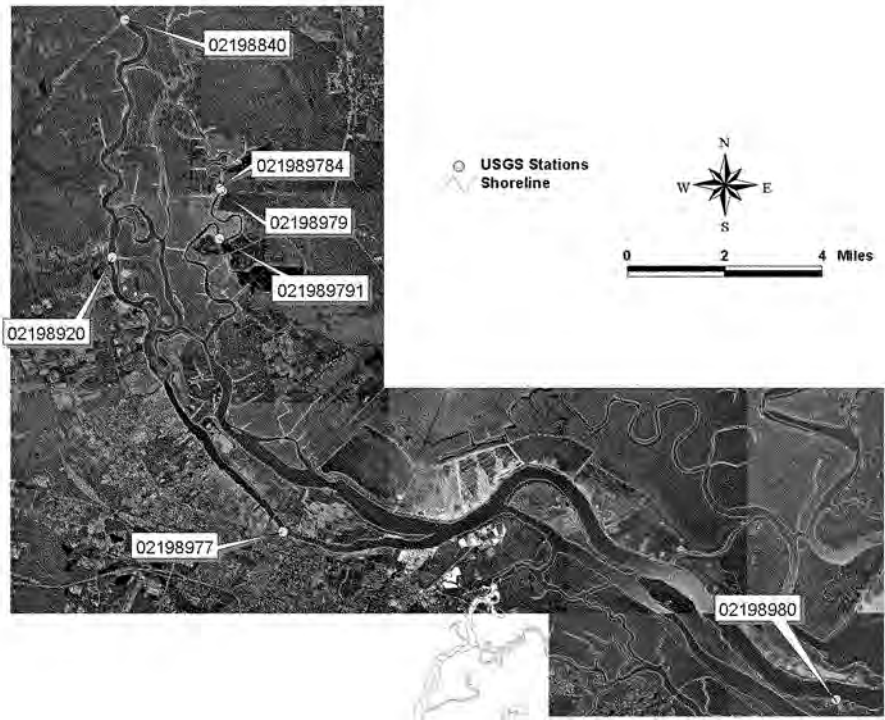


Figure 2-1 Location Map of USGS Stations in the Savannah Harbor Estuary



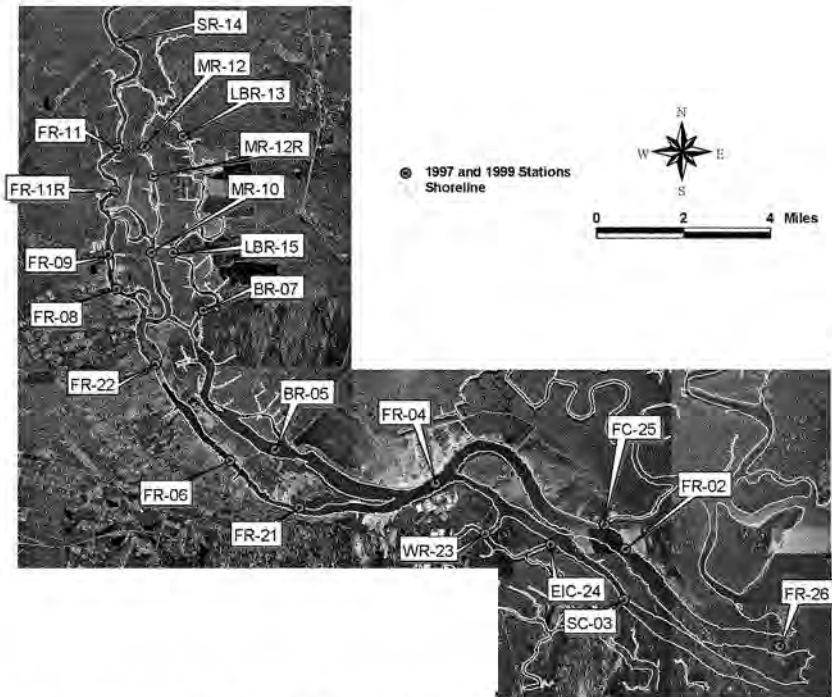


Figure 2-2 Location Map of 1997 & 1999 Stations in the Savannah Harbor Estuary

## 2.2 Database

The Water Resources Database (WRDB) was used to archive, analyze, and export water quality data for the hydrodynamic and water quality models. WRDB is a comprehensive data storage system capable of handling a vast amount of data, accommodating a wide variety of data types and diverse information, and presenting data conveniently and efficiently. WRDB was originally developed by the Georgia Environmental Protection Division (GAEPD) in association with USEPA Region 4 to address the imposing data management challenges presented by the Chattahoochee River Modeling Project. Since its inception, WRDB has been enhanced a number of times and applied to numerous projects in Region 4. A main goal of the system has been to provide data management and analysis tools to users possessing an assortment of professional specialties and a variety of software skill levels. Figure 2-3 is an example of a screen shot of the Savannah WRDB and is delivered on the compact discs included with this report.

WRDB was originally delivered to the federal agencies as part of ATM's data report (ATM, 2000). Since that time, USEPA Region 4 and Tetra Tech have not only made extensive updates to the program itself, but also to the datasets within the Savannah WRDB. A new WRDB database was developed to coincide with the final models. Additionally, the USGS data from 1997 through 2003 were input into the Savannah WRDB for salinity and water surface elevation. The water surface elevation data were



corrected to the National Geodetic Vertical Datum (or Mean Sea Level of 1929) based on USGS report adjustments (Stokes, 2002).

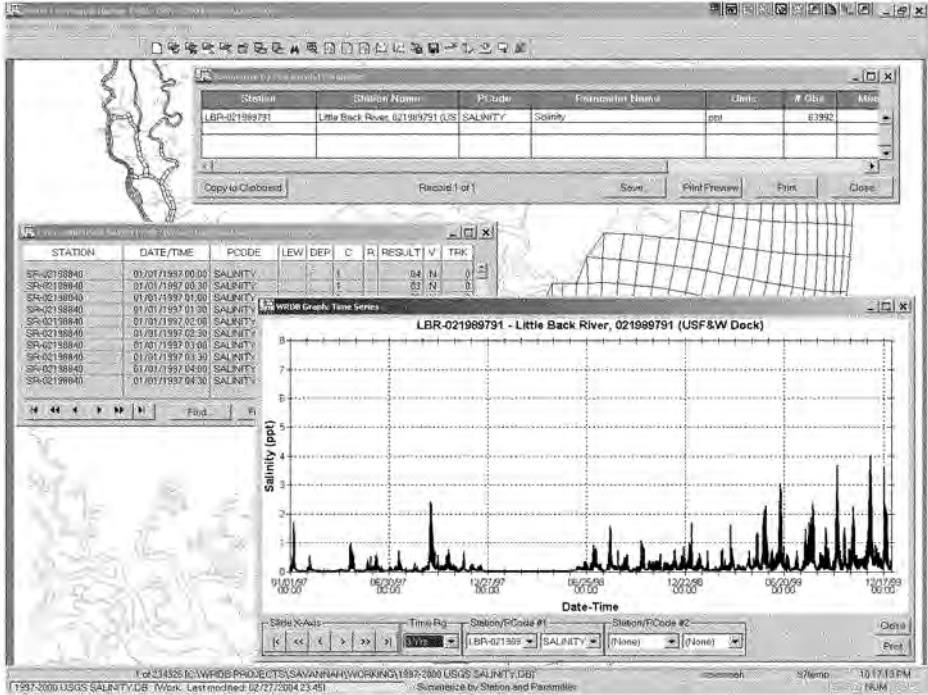


Figure 2-3 WRDB Developed for Savannah Harbor

## 2.3 Hydrology

The Clio flow gage (USGS 02198500 – Savannah River near Clio, GA) was used to evaluate the fresh water sources of water into the lower riverine and estuarine sections of the Savannah River. Tetra Tech gathered all of the available flow data from the USGS gage at Clio. The flows at this location are primarily regulated by Thurmond Dam (river mile 237.7) (see station 02194500), and by other power plants above the station. The Clio station is the closest flow gage to the upper end of the estuary and was used as the upstream boundary. As shown in Figure 2-4, flow input data includes both high and low flow periods, covering flow ranging from roughly 5,000 to 50,000 cfs as measured at Clio.

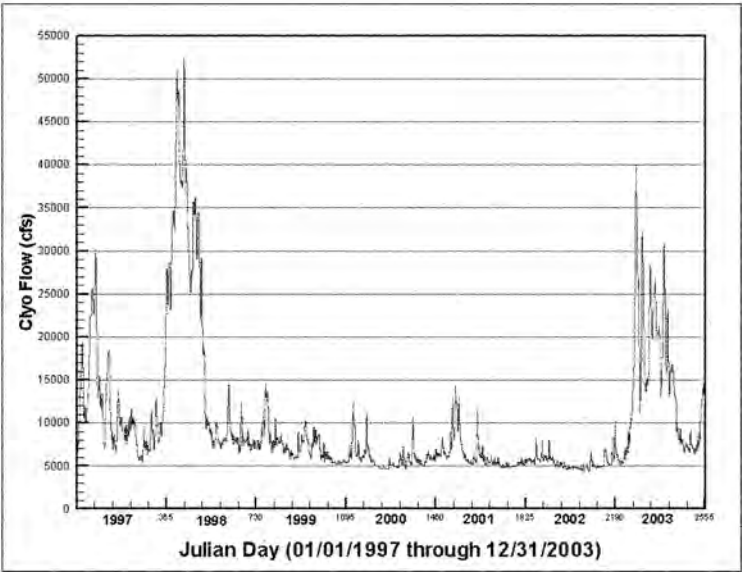


Figure 2-4 Clio Flow Data for Model Development Period



Figure 2-5 Clio Flow Percentiles for the Period of Record (1929 to present)

## 2.4 Currents

The phasing between water surface elevation and velocity was analyzed in order to determine the degree of reflection of the tidal wave entering the Savannah River Estuary. In the EFDC TMDL model report (Tetra Tech, 2004), the model results were compared to observed data evaluating whether the M2 component of the tide's observed data and model show standing wave characteristics (velocity and water surface elevation 90 degrees out of phase) or progressive wave characteristics (velocity and water surface elevation in phase). As a result of the complexity of marshes and multiple channels in the Savannah River Estuary, the tidal wave on the Front River can neither be classified as a pure progressive wave nor a pure standing wave. The system's resultant wave is a combination of multiple components of reflected and standing waves, and in some cases exhibiting resonance characterized by multiple velocity peaks in the same flood or ebb tide. Observed flood tide peak velocities lead peak water surface elevation in a range from 40 to 90 degrees in the deeper, downstream site FR-04; and 20 to 90 degrees in the shallower, upstream site FR-08. This difference in phase called "phase lag" is generally smaller during neap tides (more influence of bottom friction, and exhibiting more of the progressive wave characteristic), and generally greater during spring tides (less influence of bottom friction, exhibiting more of the standing wave characteristic). The Savannah EFDC model exhibits the same characteristics and trends in phase lag as the observed data.

The amplitude and phase of the M2 component of the time series of water surface elevation and velocity were obtained by harmonic analysis using the least squares procedure. Prior to the harmonic analysis, the data were filtered to remove non-astronomical (air pressure induced, wind setup, resonant oscillation, and storm surge) components. Raw ADCP velocity data in two-dimensions were projected to the channel for 1.5 m and highest layers, corresponding to bottom and surface velocities. Because of fluctuations in the raw data, a Chebyshev Type II filter was applied to the data using MATLAB to remove short-term oscillations. The filter period was set at 3 hours, which removes short-period variations while maintaining wave components longer than 3 hours.

To be consistent, measured velocity and water surface elevation data and model results were all filtered using the Chebyshev Type II filter. The times of the optima corresponding to flood and ebb tide peak velocities and water surface elevations were evaluated. "Phase lag" is defined as the difference in time between the flood velocity peak and the highest water surface elevation. Figure 2-6 shows an example of measuring phase lag as well as the smoothing effect of the Chebyshev Type II filter.

Flood tide phase lags were measured for observed data and model results for the period July 13-27, 1997 (Julian days 194-208), and also for the shorter periods July 14-16 representing a neap period and July 20-22, representing a spring period. Results are shown in Table 2-2 in both hours and degrees (360 degrees is equal to one full tidal cycle or 12.42 hours). Average phase lags range from 52 to 71 degrees (1.8-2.4 hours) in observed data, and 56-72 degrees (1.9-2.5 hours) in model results for these periods at FR-04 and FR-08.

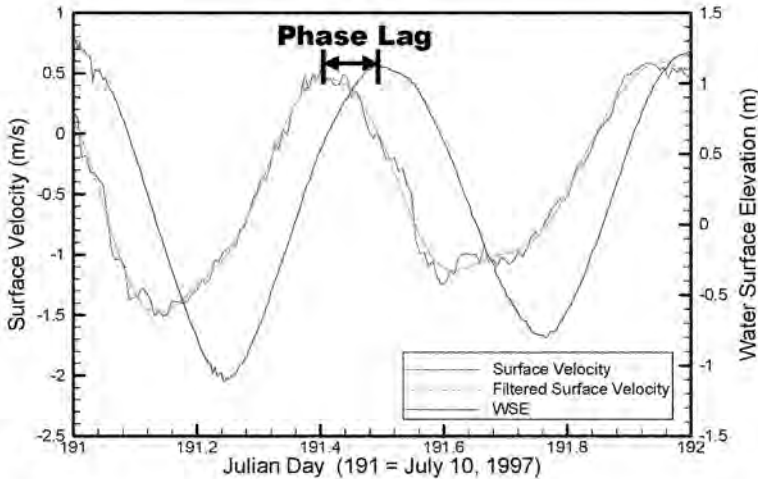


Figure 2-6 Example of Phase Lag Between Observed Surface Velocity and Observed Water Surface Elevation, Station FR-08, July 10, 1997

Table 2-2 Phase Lag of Observed Data and Model Results at FR-04 and FR-06 for Entire Tidal Cycle, Neap Period, and Spring Period in July 1997

|                    |         | FR-04    | FR-04 | FR-08    | FR-08 |
|--------------------|---------|----------|-------|----------|-------|
|                    |         | Observed | Model | Observed | Model |
| <b>Tidal Cycle</b> | Degrees | 70       | 59    | 67       | 64    |
| (Day 194-208)      | Hours   | 2.4      | 2.0   | 2.3      | 2.2   |
| <b>Spring</b>      | Degrees | 69       | 59    | 71       | 72    |
| (Day 200-203)      | Hours   | 2.4      | 2.0   | 2.4      | 2.5   |
| <b>Neap</b>        | Degrees | 52       | 56    | 59       | 60    |
| (Day 195-197)      | Hours   | 1.8      | 1.9   | 2.0      | 2.1   |

## 2.5 Salinity Intrusion

By examination of the 1997 and 1999 salinity data where surface and bottom data are available, it is evident that vertical stratification occurs. Stratification occurs when there are more saline waters (more dense) on the bottom and fresh waters (less dense) overlying, therefore, causing a "salt wedge" in the water column. Vertical mixing is decreased when this occurs. For turbulent mixing to begin, the tidal energy in the system must be raised to increase the potential energy of the water column (Fischer, 1979). Figure 2-6 demonstrates the effect of less tidal energy with the display of water velocity (currents) on the left-hand axis and salinity for surface and bottom measurements on the right-hand axis. These comparisons were made to compare FR-04 and -06 during 1999 because this is the best data signal of combined currents and salinity for 1997 and 1999. It is obvious from Figure 2-7 that the stratification events occur sharply on August 16, 1999 and September 14, 1999. Progressing from a neap tide to a

spring tide, there is a subsequent increase in tidal velocity that overcomes the energy in the stratified environment which then mixes the water column vertically.

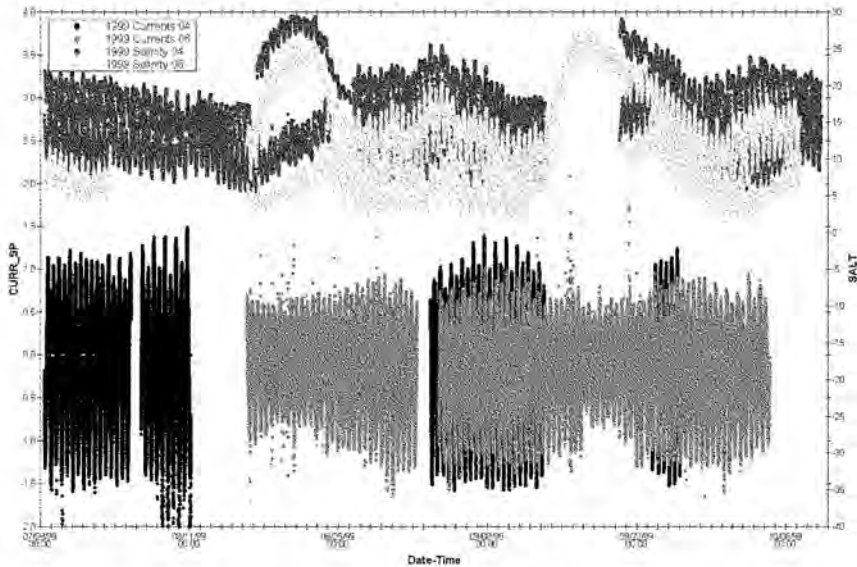


Figure 2-7 Salinity Stratification and Destratification Due to Neap and Spring Tidal Events at FR-04 and -06

## 2.6 Summer 1999 Continuous Data QA/QC

USGS performed additional quality assurance/quality control (QA/QC) on the summer 1999 continuous dataset by working with the raw data files of water level, specific conductance, temperature, and dissolved oxygen. The data were collected by ATM, Inc. for the GPA in 1999 and reported in 2000 (ATM, 2000). In September 2005, the EPA Region 4 requested that the USGS process the raw data and document the corrections based on the servicing profiles collected at each instrument. Data processing consisted of: (1) assigning a unique USGS station number (consisting of latitude and longitude) and name, then creating a station header files in the National Water Information System (NWIS) database, (2) writing DECODES for the raw time-series data and populating NWIS, (3) evaluate the ATM site-visit files, the vertical-profile files, and initial deployment data, in order to determine shifts corrections, (4) applying shift corrections and deleting erroneous unit data, and (5) generating primary computations, unit data plots, and station analysis for the QA package. The final QA/QC data were delivered to Tetra Tech on January 15, 2006.

### 3.0 EFDC HYDRODYNAMIC MODEL

#### 3.1 Selection of Model

In developing a hydrodynamic model for the Savannah Harbor Estuary, it is critical that the model must meet the expectations discussed in the introduction section of this document. The Environmental Fluid Dynamics Code (EFDC) was selected by EPA to perform the hydrodynamic simulations because it was able to fulfill all of the requirements presented in the goals of the study. EFDC has been applied on many waterbodies within USEPA Region 4 for TMDL and permit modeling projects on complex systems such as Mobile Bay, AL; Neuse River and Estuary, NC; Brunswick Harbor, GA; Fenholloway River and Estuary, FL; Loxahatchee River and Estuary, FL; Indian River Lagoon, FL; Lake Worth Lagoon, FL; Florida Bay, Lake Okeechobee, FL; Cape Fear River, NC; and St. Johns River, FL. EFDC has proven to capture the complex hydrodynamics in systems similar to that of Savannah Harbor and is currently being applied by Tetra Tech to the Charleston Harbor, South Carolina for the SC DHEC.

The EFDC model is a part of the USEPA TMDL Modeling Toolbox due to its application in many TMDL-type projects. As such, the code has been peer reviewed and tested and has been freely distributed for public use. EFDC was developed by Dr. John Hamrick and is currently supported by Tetra Tech for USEPA Office of Research and Development (ORD), USEPA Region 4, and USEPA Headquarters. The EFDC model is nonproprietary and publicly available through USEPA Region 4 and USEPA ORD from the Watershed and Water Quality Modeling Technical Support Center (<http://www.epa.gov/githens/wqisc/index.html>). The models, tools, and databases in the TMDL Modeling Toolbox are continually updated and upgraded through TMDL development in Region 4. Tetra Tech is currently supporting the development of the toolbox with a grid generator and EFDC pre-processor (EFDCView).

With many of the EFDC applications in Region 4 being tied to the regulatory TMDL process, Tetra Tech has delivered various applications of the model to state and federal personnel to run the model for regulatory management decisions.

Although a number of models provide some of the features necessary for modeling hydrodynamics, water quality, and sediment transport in the Savannah River Estuary, the EFDC hydrodynamic and sediment transport model linked with the WASP water quality model provides the most appropriate combination of features necessary for this study.

#### 3.2 History of Model

The EFDC model comprises an advanced three-dimensional surface water modeling system for hydrodynamic and reactive transport simulations of rivers, lakes, reservoirs, wetland systems, estuaries and the coastal ocean. The modeling system was originally developed at the Virginia Institute of Marine Science as part of a long-term research program to develop operational models for resource management applications in Virginia's estuarine and coastal waters (Hamrick, 1992). Since the EFDC model is public domain, with current users including universities, governmental agencies and engineering consultants. The following sub-sections describe the model's capabilities and previous applications and its theoretical and computational formulations.

The EFDC model's hydrodynamic model component is based on the three-dimensional shallow water equations and includes dynamically coupled salinity and temperature transport. The basic physical process simulation capabilities of the EFDC hydrodynamic component are similar to those of the Blumberg-Mellor or POM model (Blumberg & Mellor, 1987), the U.S. Army Corps of Engineers' (USACOE) CH3D-WES model (Johnson, et al., 1993), and the TRIM model. Notable extensions to the

EFDC hydrodynamic model include representation of hydraulic structures for controlled flow systems, vegetation resistance for wetland systems (Hamrick and Moustafa, 1996), and high frequency surface wave radiation stress forcing for nearshore coastal simulations.

EFDC is a multifunctional, surface-water modeling system, which includes hydrodynamic, sediment-contaminant, and eutrophication components. The EFDC model is capable of 1, 2, and 3D spatial resolution. The model employs a curvilinear-orthogonal horizontal grid and a sigma or terrain following vertical grid. The EFDC model's hydrodynamic component employs a semi-implicit, conservative finite volume-finite difference solution scheme for the hydrostatic primitive equations with either two or three-level time stepping. (Hamrick, 1992). The semi-implicit scheme is based on external mode splitting with the external mode being implicit with respect to the water surface elevation and the internal mode being implicit with respect to vertical turbulent momentum diffusion. Advective and Coriolis-curvature accelerations in both the external and internal modes are represented by explicit conservative formulations. Salinity and temperature transport are simultaneously solved with the hydrodynamics and dynamically coupled through an equation of state. The hydrodynamic component includes two additional scalar transported variables, a reactive variable which can be used to represent dye or pathogenic organisms, and a shell fish larvae variable which includes a number vertical swimming behavior options. Scalar transport options include a number of high accuracy advection schemes including flux corrected MPDATA and flux limited COSMIC. Additional hydrodynamic component features include, the Mellor-Yamada turbulence closure formulation, simulation of drying and wetting, representation of hydraulic control structures, vegetation resistance, wave-current boundary layers and wave induced currents, and dynamic time stepping. An embedded single and multi-port buoyant jet module is included for coupled near and far field mixing analysis.

The EFDC hydrodynamic model can run independently of a water quality model. The EFDC model simulates the hydrodynamic and constituent transport and then writes a hydrodynamic linkage file for a water quality model such as the WASP7 model. This model linkage, from EFDC hydrodynamics to WASP7 water quality, has been applied on many USEPA Region 4 projects in support of TMDLs and has been well tested (Wool, 2003). EFDC is also directly linked to the Corps of Engineers Engineering Research and Development Center's CE-QUAL-ICM.

### **3.3 Peer Review**

All components of the EFDC model have been extensively validated over the course of the model's 15-year existence with more than 80 applications. The model has been extensively peer reviewed, as evidenced by 12 peer reviewed journal articles and 17 peer reviewed conference proceedings articles. There were no code modifications required for the Savannah Harbor application.

### **3.4 Technology Transfer**

The technology transfer will occur with the distribution of this report. There are two compact discs (CDs) included in the back of the report. The Savannah Harbor WRDB database is on CD1 that includes most of the model comparison data files. On CD2, the EFDC model input files, model code, model output files, model executables, and GIS files are included. The EFDC model output and database files can be viewed in a post-processor called the Model Visualization Enhancement Module (MOVEM). There was a significant amount of effort by USEPA Region 4, USPEA ORD, and Alex Comer (software developer) to include the modeling statistics and percentiles in the MOVEM post-processor so that the Federal Expectations criteria can be examined directly by the technical reviewers.



## 4.0 EFDC APPLICATION TO THE SAVANNAH RIVER ESTUARY

The Savannah River Estuary is a highly complex estuarine system characterized by a branching channel network and extensive intra-tidal marsh areas. The combination of an energetic tidal environment and significant river basin drainage area result in a highly variable salinity regime that is characteristic of stratified estuaries. Vertical density stratification significantly influences dissolved oxygen dynamics while both stratification, the landward intrusion of salinity, and the associated sub-tidal residual circulation strongly influence sedimentation dynamics. The complexities of the branching channel system dynamically coupled with the intra-tidal marshes result in complex current amplitude and phase distributions, which further complicate the transport dynamics of the system. Increasing the depth of the navigational channel can affect impacts on local vertical mixing, increase landward salinity intrusion, and alter existing patterns of sediment deposition and resuspension.

Predicting the transport of salinity, sediment, and water quality constituents in the Lower Savannah River necessitates the use of a three-dimensional modeling system, which includes hydrodynamic, sediment transport, and water quality components. The branching channel system and the presence of intra-tidal marshes further require a modeling system capable of representing complex open water regions dynamically coupled with marshes which dry and wet during the tidal cycles.

### 4.1 Simulation Period

The EFDC modeling files were developed with the ability to run the model for seven years. The input files start on January 1, 1997, and were extended through December 31, 2003. When the 2004 data become available from the USGS, they can be extended through 2004. The model can be run for any time period during those dates with an appropriate spin-up period of 30 days.

### 4.2 Model Grid and Bathymetry

The model grid was enhanced to include more cells in the navigation channel. There are now 931 horizontal cells that extend upstream to Clyo, Georgia (~ 61 miles from Fort Pulaski) and downstream to the Atlantic Ocean (~17 miles offshore from Fort Pulaski). If the marsh cells are included, there are 947 total cells. The man-made connections were included such as McCoys Cut, Rifle Cut, Drakies Cut, New Cut as closed, and the sill of the Tide Gate. The as-builts for the tide gate show a structure 645 feet in width with a 9-foot sill below Mean Low Water (MLW). The structure has 14 openings each measuring 22 feet high by 40 feet wide, with the bottom sill at elevation -9 feet. The shipping channel is better defined compared to the TMDL grid and was matched with the USACE channel configuration. Most of the navigation channel is represented as one cell wide from toe to toe and then another grid cell on either side to represent the sides of the channel. Additional grid cells were added at the Kings Island Turning basin and the Elba Island Bight areas. Figure 4-1 shows the enhanced grid with a closer view in Figure 4-2 of the upper estuary.

The bathymetry data were obtained from several sources. There is not one particular year in which the bathymetry data were measured throughout the system; therefore, sections of bathymetry files were constructed to form a bathymetry dataset for the river and harbor. The bathymetry sources are as follows:

- USACE Annual Surveys (1999 and 2002);
- USGS SNWR (2004) for the Back, Middle, and Little Back Rivers;
- USACE Upstream of I-95 (1999); and



- NOAA Surveys (1980s) for the offshore non-channel and south channel areas.

The annual surveys were compared and it was determined that 1999 and 2002 do have some differences in the navigation channel. The differences depend on the line of the survey because they usually do not follow the exact same ship tracking line. Also, it depends on when the survey occurred (just after dredging or an extended time after dredging).

Model bottom elevation was determined based on the 2002 survey data in the harbor and based on river cross-sections in the upper extents of the grid. The invert of the model at Clio is at +0.5 meters NGVD with the invert of the harbor near -15 to -16 meters. The slope change from Clio to the I-95 Bridge is approximately six meters with an additional nine meters to the Front River and Back River confluence near Fort Jackson. The bottom elevation can be reviewed in the "dxdy.inp" file.

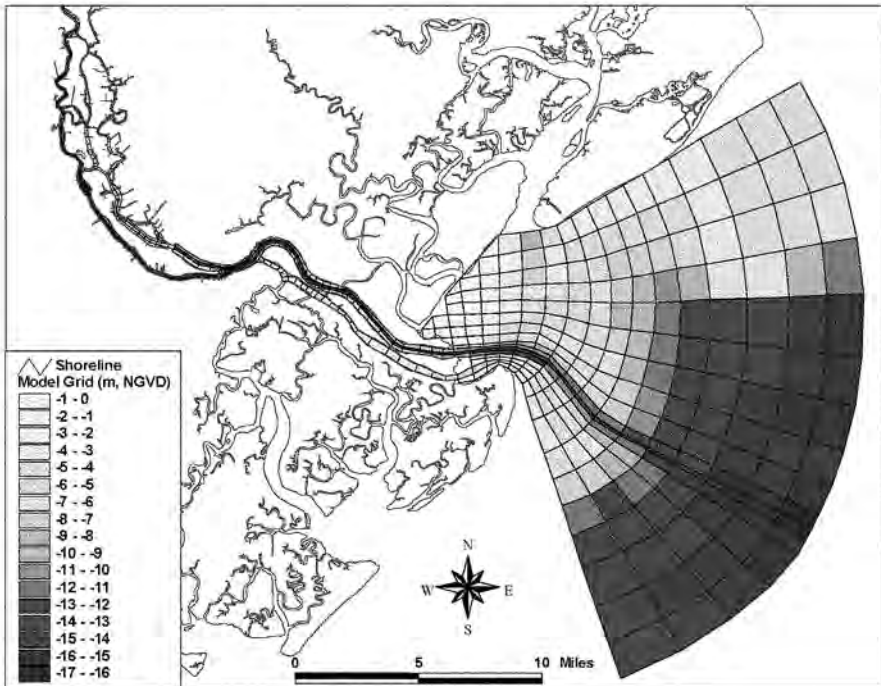


Figure 4-1 Model Grid and Bathymetry

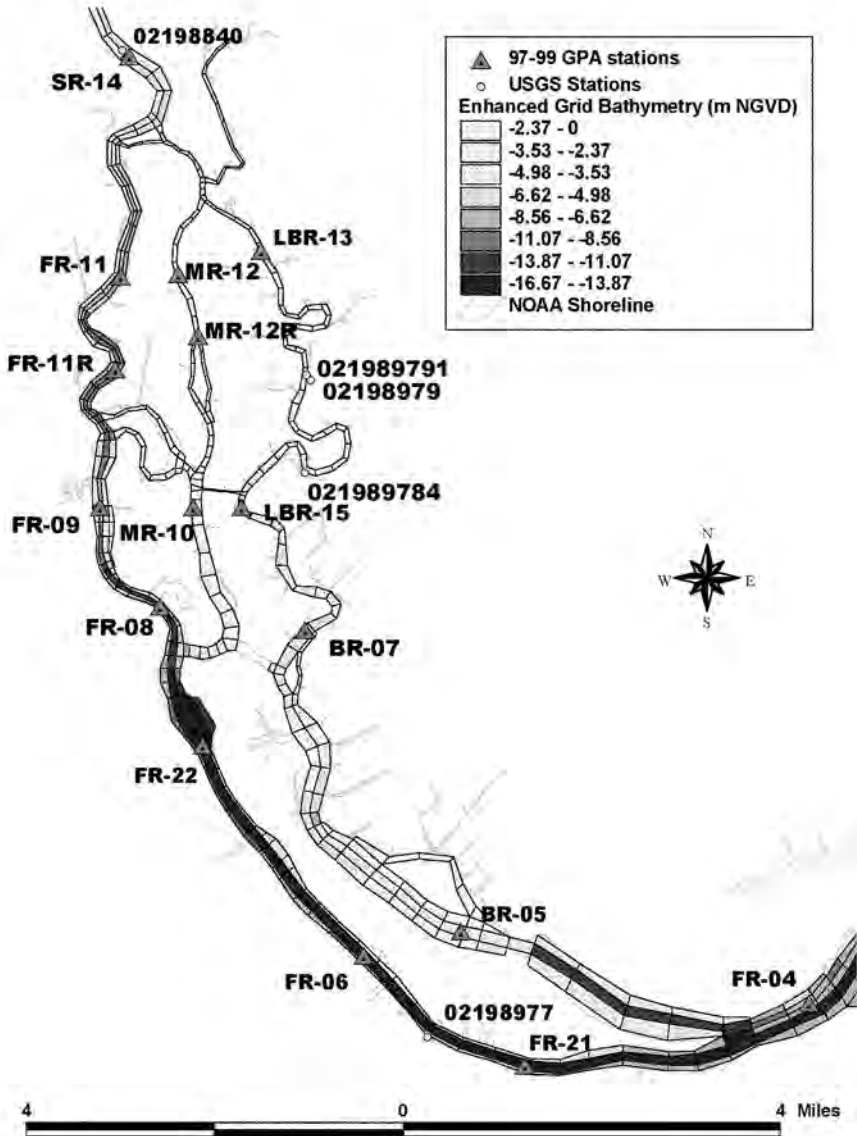


Figure 4-2 Model Grid and Bathymetry in the Upper Estuary

The 2004 USGS survey is shown in Figure 4-3. These data points were essential for enhancing the representation of the bathymetry in the Back, Little Back, and Middle River areas.

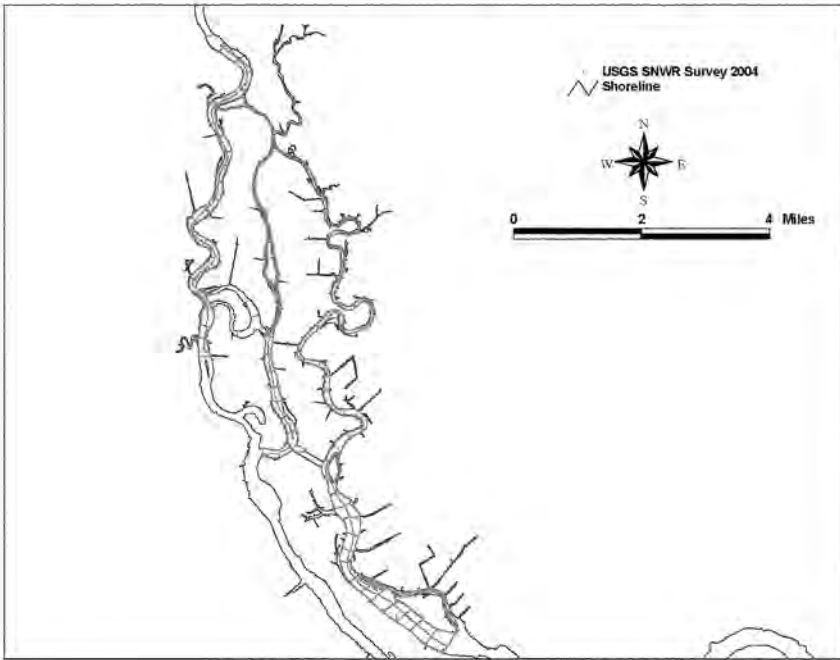


Figure 4-3 USGS 2004 Survey Points in the Savannah National Wildlife Refuge (SNWR)

After receiving the electronic GIS files of the 2002 annual survey from the USACE Savannah District, the channel and side-channel areas were re-examined to not only examine the cross-sectional area of the channel, but also examine the longitudinal aspect of the bathymetry. Figure 4-4 shows that the bottom of the navigation channel is not smooth and can vary by 0.5 meters from station to station. The USACE stationing is in 1,000-foot increments. For the enhanced model grid, five cross-section inverts were averaged to develop the channel depths used in the model. The green line in Figure 4-4 was used to represent the channel in the enhanced model grid. According to the measured bathymetry soundings along the Front River (USGS, 2004), the channel thalweg alternates from bank to bank and the channel is deepest on the outside of channel bends. In order to properly represent this for optimal model results, the thalweg was considered to be the center cell in the model grid. This is shown in Figure 4-5 with  $I = 14$  being the center cell (thalweg) and  $I = 13$  and  $15$  the side cells.

The 2002 and 1999 datasets were compared by analyzing cross-sections between the two surveys at many locations. Although there were some differences in alignment of the cross-sections, there was not a difference between the two surveys. Also, the survey data are grouped and averaged according to the model grid cell, and there was not a difference between 1999 and 2002 once this averaging occurred. Since dredging is a continuous operation in the navigation channel from year to year, the goal was to have a bathymetry that represents the current channel configuration, or depth, since the last deepening in 1994.

It was determined that the 1999 and 2002 annual surveys are interchangeable in the model grid and best represent the existing (calibration) conditions.

Tetra Tech also compared the variations across the width of the cross-section. The navigational channel is not a typical trapezoidal channel due to the bends in the navigational channel and associated deposition and scouring. Figures 4-6 and 4-7 show a comparison of the cross-sectional variation between the 1999 and 2002 USACE surveys. The 2002 survey was selected for use in the grid bathymetry because we were able to obtain the entire dataset electronically whereas the 1999 we only had the partial channel. Also, the 2002 survey appeared to be consistent with the 2004 USGS survey for the Back, Little Back, Middle, and Front Rivers. The depth selected for each cell represents the average depth condition for the entire cell.

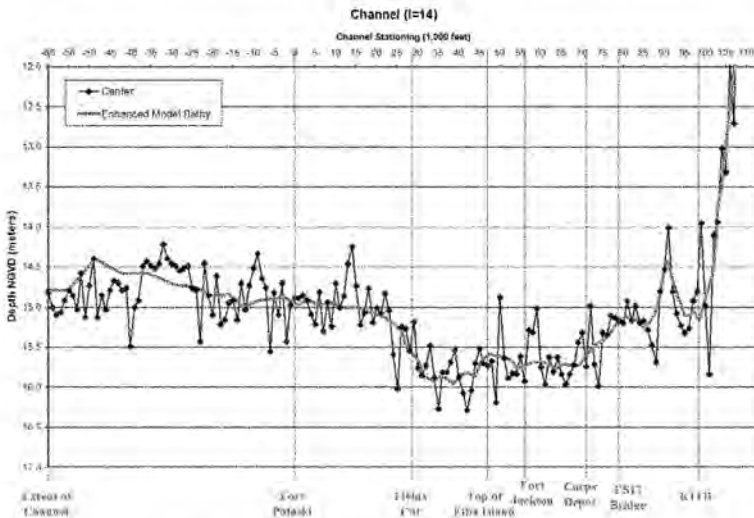


Figure 4-4 Longitudinal Plot of the Navigation Channel

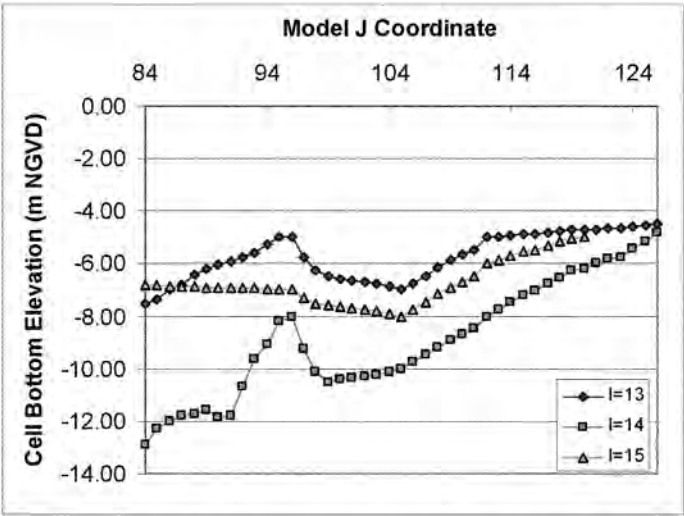


Figure 4-5 Longitudinal Bottom Elevations from Houlihan Bridge to I-95 Bridge (I = 14 is the center cell and I = 13 and 15 are the side cells)

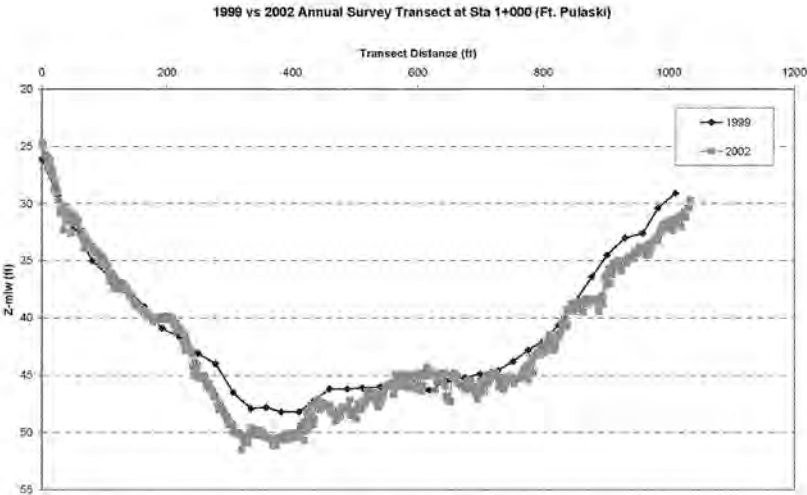


Figure 4-6 Cross-Sectional Comparison near Fort Pulaski of the 1999 and 2002 Annual Surveys by the USACE

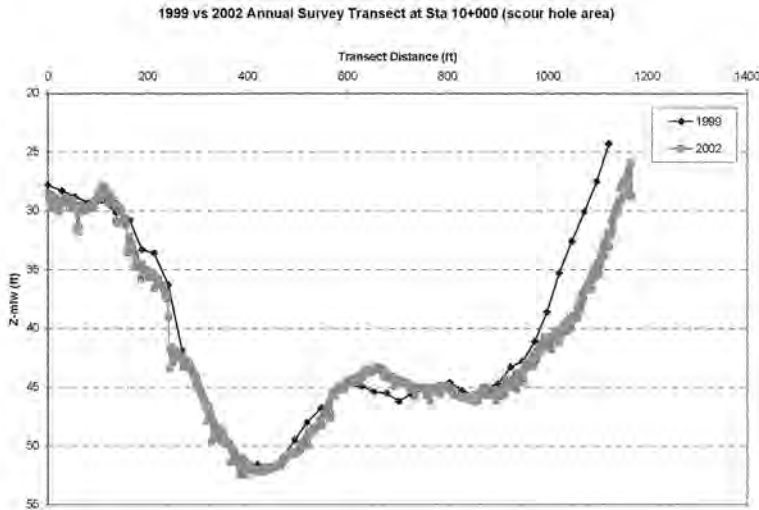


Figure 4-7 Cross-Sectional Comparison near New Channel Bend of the 1999 and 2002 Annual Surveys by the USACE

#### 4.2.1 Grid Convergence Test

The federal agencies believe that a grid convergence test should be completed to ensure that the model is defensible and convergence testing of the model must be performed on the application to the Savannah Harbor.

A model grid convergence test was performed to determine the appropriate level of grid resolution for numerical solution, where a finer grid would not produce substantially different model predictions. The model grid convergence test results are shown in Appendix A. A simple approach was taken to develop the grid convergence test. The TMDL model had been developed on a coarse model grid (655 horizontal cells) and calibrated to the same datasets. The enhanced grid has more cells (931) and represents a finer grid. The TMDL model grid and the enhanced model grid were run with two depth scenarios, 7 and 10 meters. The entire model domain was run with both of these depth scenarios and compared. The 7-meter TMDL grid was compared to the 7-meter enhanced grid to determine if there are differences based on the grid resolution. The same analysis was done with the 10-meter model runs.

Appendix A shows that there are some areas where the TMDL and enhanced grids show differences. The closer to the ocean boundary obviously, the better the comparison. Also, when the 7- and 10-meter depths are put in the grid for the entire model domain, it allows more salinity to intrude into the system. Both grids represent the intrusion equally as well with differences in the upper part of the system. The approach shows that the two grids represent the processes occurring in the system with differences attributed to the widths and lengths of the grids being slightly different.

### 4.3 Model Coefficients

The main EFDC modeling coefficients are bottom roughness, bathymetry, and vertical mixing.

#### 4.3.1 Bottom Roughness

The bottom roughness of the EFDC Savannah Harbor model was applied as a constant of 0.02 m in the estuary. In the upper riverine sections, the bottom roughness was higher near 0.14 m. Bottom roughness is different from a friction coefficient because it is the logarithmic boundary layer roughness height in meters. The solution of the momentum equations requires the specification of the bottom stress  $\tau_b$ .

$$\tau_b = \rho u_*^2 = c_b \rho U^2$$

where  $u_*$  is the friction or shear velocity,  $c_b$  is the bottom stress coefficient (friction coefficient) and  $U$  is the flow velocity at the bottom layer. Assuming a logarithmic velocity profile between the solid bottom and the middle of the bottom cell layer gives the bottom stress coefficient:

$$c_b = \kappa^2 \left[ \ln \left( \frac{H}{2z_0} \right) \right]^{-2}$$

where  $z_0$  is the dimensional bottom roughness height,  $\kappa$  is von Karman constant and  $H$  is the height of the bottom layer.

The bottom roughness forms a hierarchy from smallest-to-largest that include typical:

- Nikuradse roughness – sediment grain roughness
- Biogenic roughness – mounds and burrows that were created by benthic organisms and vegetation
- Saltation roughness – often dominates on sandy coastal areas
- Bedform roughness- characterized by the height, wavelength and roughness of sand ripples.

The value of 0.02 m roughness is reasonable in Savannah Harbor. The 0.02 m was used for all EFDC applications in the James River where the model did very well in predicting salinity, current meter transects at James River Bridge, and frontal structure at Newport News Point. Conversely, the James model used an approximately 400 m grid and much of the  $z_0$  may be sub-grid scale topography. For the Savannah model, the attribution to lateral effects may have some bearing since the lateral resolution may not capture resistance of very shallow areas. As to the sensitivity, there would not be much change between 0.015, 0.02, and 0.025 and typical estuary applications for  $z_0$  range from 0.0005 to 0.02 (Hamrick, 2005). The rationale for the larger values is that, in addition to representing the actual bed grain scale roughness, the  $z_0$  accounts for larger scale effects which could include bed form drag, drag due to obstacles in flow, and drag implied by sub-grid scale topographic variability. The  $z_0$  is basically calibrated to achieve correct amplitude attenuation and phase propagate for the tide. With this in mind, other features such as unaccounted marsh storage, etc. could influence the choice of  $z_0$  globally to achieve the calibration to the tide. Of course, in an estuary where there is little apparent propagation and the tide has more of a standing wave characteristic, the tidal calibration can be relatively insensitive to  $z_0$ . In this case, larger values of  $z_0$  would tend to be used to increase vertical mixing if necessary to calibrate to stratification and length of salinity intrusion. In a strongly stratified estuary, such as Savannah, the turbulence model can tend to over stratify since phenomena such as internal wave breaking, which would enhance mixing, are not represented.

#### 4.3.2 Vertical Mixing

EFDC calculates vertical eddy diffusivity and vertical kinematic viscosity based on the Mellor-Yamada (M-Y) turbulence closure scheme developed at Princeton University in the 1970s by Dr. George Mellor and T. Yamada and modified by Galperin *et al* (1988). The EFDC implementation exactly follows that maintained by Dr. Mellor in the Princeton Ocean Model (POM). The M-Y Turbulence Model is the most widely used prediction scheme for turbulent transport in estuary and ocean models. No equations are needed externally to force vertical mixing in EFDC so the model can be used in a predictive mode to simulate the physics of mixing.

The M-Y turbulence closure scheme solves the two 3-dimensional transport equations for turbulent kinetic energy and the turbulent length scale. The vertical turbulent viscosity and diffusivity are analytically derived functions of the turbulent kinetic energy, length scale, and turbulence intensity based Richardson Number. The turbulence closure model uses nine parameters, which were determined by M-Y using extensive data from laboratory studies of turbulent shear flow (A1, A2, B1, B2, C1, C2, E1, E2, and E3). These nine parameters are located in Card 13 of the "efdc.inp" file. The turbulent kinetic energy equation is shown below.

$$\begin{aligned} & \partial_t (m_x m_y H q^2) + \partial_x (m_y H u q^2) + \partial_y (m_x H v q^2) + \partial_z (m_x m_y w q^2) \\ & = \partial_z \left( m_x m_y \frac{A_q}{H} \partial_z q^2 \right) - 2 m_x m_y \frac{H q^3}{B_l l} \\ & + 2 m_x m_y \left( \frac{A_v}{H} \left( (\partial_z u)^2 + (\partial_z v)^2 \right) + \eta_p c_p D_p (u^2 + v^2)^{3/2} + g K_v \partial_z b \right) + Q_q \\ & q^2 = 2 \times \text{turbulent kinetic energy} \end{aligned}$$

The turbulent length scale equation is shown below. Three of the nine parameters discussed above can be seen as E1, E2, and E3 below. The other parameters do not appear if the equations above or below because they are used in the turbulent viscosity ( $A_v$ ), turbulent diffusivity ( $K_v$ ), and turbulent intensity Richardson Number ( $R_q$ ).

$$\begin{aligned} & \partial_t (m_x m_y H q^2 l) + \partial_x (m_y H u q^2 l) + \partial_y (m_x H v q^2 l) + \partial_z (m_x m_y w q^2 l) \\ & = \partial_z \left( m_x m_y \frac{A_q}{H} \partial_z (q^2 l) \right) - m_x m_y \frac{H q^3}{B_l} \left( 1 + E_2 \left( \frac{l}{\kappa H z} \right)^2 + E_3 \left( \frac{l}{\kappa H (1-z)} \right)^2 \right) \\ & + m_x m_y E_1 \left( \frac{A_v}{H} \left( (\partial_z u)^2 + (\partial_z v)^2 \right) + g K_v \partial_z b + \eta_p c_p D_p (u^2 + v^2)^{3/2} \right) + Q_l \end{aligned}$$



#### 4.4 Model Boundary Conditions

The model boundary conditions for the EFDC model consisted of the following components:

- offshore salinity, temperature, and water surface elevation;
- upstream flow and temperature;
- adjacent marsh boundary areas; and
- meteorological forcing conditions.

These boundaries are straightforward and developed in a way that is consistent with the continuous records available from the USGS. Ideally, the EFDC model can be run for any time period by gathering the Clio flows and temperature for the upstream boundary and water surface elevation and temperature at the downstream boundary.

The water surface elevation data collected by the National Ocean Survey at Fort Pulaski were used as the initial approximation of the offshore boundary conditions for the hydrodynamic model. These data were obtained in feet of MLLW. The available USGS data upstream of Savannah River have units of feet NGVD. The conversion of units and adjustment of water surface elevation boundary conditions were made to fit the Fort Pulaski water surface elevation dynamics in magnitude and phase.

##### 4.4.1 Offshore Boundary

The offshore boundary of the grid is approximately 17 miles from river mile 0.0 as shown in the previous Figure 4-1. River mile 0.0 is at the mouth of the river and entrance channel near Oysterbed Island.

The offshore boundary for water surface elevation consisted of examining the data collected by the USGS at Fort Pulaski (02198980). These data were obtained in feet of MLLW and used as the initial approximation of the offshore boundary conditions for the hydrodynamic model. The conversion of units into NGVD and adjustment of water surface elevation values were made to reach an acceptable agreement of the model versus data at Fort Pulaski.

The offshore salinity boundary was determined by examining three data sources: (1) data collected by the Skidaway Institute of Oceanography from a partnered field research study called the South Atlantic Bight Synoptic Offshore Observational Network (SABSOON); (2) the Carolinas Coastal Ocean Observing and Prediction System (Caro-COOPS) based upon an instrumented array of coastal and offshore moorings; and (3) offshore data collected by MACTEC during the offshore LTBOD samples on September 24, 2003.

The SABSOON is a real-time observational network that has been developed on the U.S. Southeastern continental shelf and the sites are shown in Figure 4-8. There are eight large offshore platforms currently operated by the U.S. Navy for flight training and are being instrumented to provide a range of oceanographic and meteorological observations on a continuous real-time basis. The historical measurements at R2 range from 33 to 36 ppt.

MACTEC collected a sample offshore at a site called "Southern Ocean Sample" and the salinity was 34.6 ppt on September 24, 2003.

The Caro-COOPS site that is closest to the Savannah Harbor model grid is FRP2 Fripp Nearshore. The location of the stations can be found at [http://nautilus.baruch.sc.edu/carocoops\\_website/index.php](http://nautilus.baruch.sc.edu/carocoops_website/index.php). The data from August 2003 to March 2005 ranged from 30 to 35 ppt.

Ultimately, the model performance was used to derive the appropriate boundary condition. Data collected at FR-26 near Fort Pulaski during 1999 were not appropriate because of fresh water mixing and

stratification occurring at this location. There were often times that a variable salinity boundary would have performed better for the salinity statistics in 1999 or 1997, but it was deemed more defensible to have a constant boundary especially for multiple year runs or for model predictions outside the limits of the data. The SABSOON and Caro-COOPS data networks were not operating during 1997 and 1999. The data at R2 in the SABSOON network had near surface and near bottom (~23 meters) instruments that did show a difference of 3-5 ppt between the surface and bottom at times. Therefore, the EFDC calibrated hydrodynamics used a 32.5 ppt at the surface and 35 ppt at the bottom with 0.5 ppt increments in layers two through six.

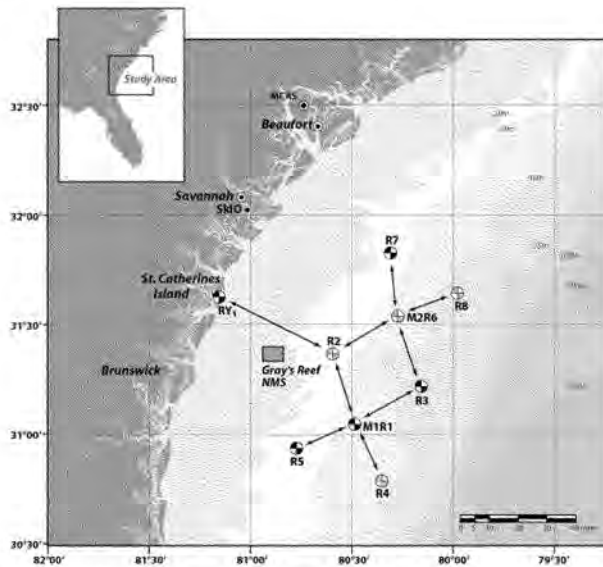


Figure 4-8 SABSOON Stations in the Atlantic Ocean

#### 4.4.2 Upstream Boundary

The upstream boundary of the grid at Clio, Georgia is approximately 61 miles from river mile 0.0. The USGS flow data shown in Figure 2-4 were used as the upstream boundary forcing. The flow data were 30-minute and 1-hour intervals depending on the time period and data retrieved from USGS. The upstream temperature data were retrieved from USGS and measured as part of GAEPD's trend monitoring network and are plotted in Figure 4-9.

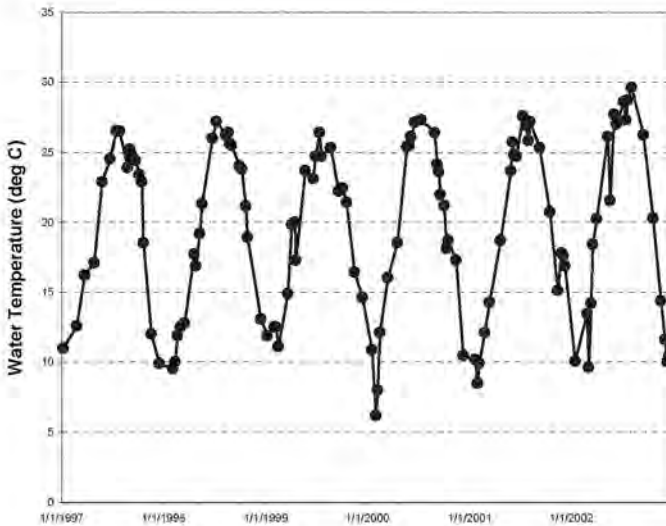


Figure 4-9 Water Temperature at Clio for 1997 through 2002

#### 4.4.3 Marsh Boundaries

The initial model runs of the enhanced grid were performed without the marsh areas. Overall, the salinity calibration on the Front River was very good without including these areas. After careful examination of the salinity influences on the Middle and Little Back Rivers, it was determined that the marsh areas were critical to capturing the salinity trends in the upper part of the estuary. Also, the marsh areas would be more critical for the water quality model. Since the EFDC model calibration was mostly successful without the marsh areas, a simple but comprehensive solution was developed.

Tetra Tech pulled the existing marsh area coverages from the ATM "Tidal Marsh Studies Data Report" Volumes 1 and 3 (2003). The surface areas of the river, marsh, and feeder channels were determined for 10 separate marsh zones called Q zones. These 10 zones were delineated based on vegetation zones measured by ATM's field studies. In Volume 1 of the ATM marsh data report, the flooding frequency, duration, and average depth by Q zone were reported and are summarized in Table 4-1. In Volume 3 of the ATM marsh report, the total acreages were calculated for secondary canals, river channels, and marshes for each vegetation cell, or Q zone. Total volumes were then calculated based on areas and depths and are presented in Table 4-2.

Table 4-1 Flooding Frequency, Duration, and Average Depth by Q Zone

| River | Q zone | Flooding % Freq | Flooding % Duration | Avg Depth (ft) | Avg Depth (m) | Elev (ft) NGVD |
|-------|--------|-----------------|---------------------|----------------|---------------|----------------|
| FR    | Q1     | 30.9            | 5.6                 | 0.39           | 0.12          | 5.05           |
| BR    | Q2     | 91.2            | 22.6                | 0.81           | 0.25          | 3.69           |
| BR    | Q3     | 63.2            | 14.7                | 0.60           | 0.18          | 4.29           |
| BR    | Q4     | 75.0            | 19.2                | 0.69           | 0.21          | 4.20           |
| MR    | Q5     | 62.9            | 16.3                | 0.65           | 0.20          | 4.47           |
| MR    | Q6     | 56.5            | 12.9                | 0.51           | 0.16          | 4.64           |
| FR    | Q7     | 91.8            | 26.8                | 0.95           | 0.29          | 3.83           |
| BR    | Q8     | 60.5            | 13.8                | 0.46           | 0.14          | 4.68           |
| MR    | Q9     | 79.6            | 21.5                | 0.70           | 0.21          | 4.18           |
| MR    | Q10    | 75.2            | 19.7                | 0.72           | 0.22          | 4.31           |

Table 4-2 Marsh Area and Volume Calculations used in the EFDC Model

| Q zone | Waterbody | Area (acres) | Area (m <sup>2</sup> ) | Depth (m) | Volume (m <sup>3</sup> ) |
|--------|-----------|--------------|------------------------|-----------|--------------------------|
| Q1     | CHANNEL   | 15           | 59,870                 | 1.2       | 72,994                   |
|        | MARSH     | 490          | 1,981,290              | 0.12      | 235,520                  |
| Q2     | CHANNEL   | 187          | 755,863                | 1.2       | 921,549                  |
|        | MARSH     | 2,190        | 8,861,825              | 0.25      | 2,187,878                |
| Q3     | CHANNEL   | 89           | 360,733                | 1.2       | 439,806                  |
|        | MARSH     | 1,363        | 5,516,392              | 0.18      | 1,008,838                |
| Q4     | CHANNEL   | 12           | 46,544                 | 1.2       | 56,746                   |
|        | MARSH     | 336          | 1,359,504              | 0.21      | 285,920                  |
| Q5     | CHANNEL   | 8            | 33,334                 | 1.2       | 40,641                   |
|        | MARSH     | 210          | 851,168                | 0.20      | 168,633                  |
| Q6     | CHANNEL   | 8            | 33,080                 | 1.2       | 40,331                   |
|        | MARSH     | 489          | 1,977,169              | 0.16      | 307,347                  |
| Q7     | CHANNEL   | 9            | 35,485                 | 1.2       | 43,264                   |
|        | MARSH     | 247          | 1,000,219              | 0.29      | 289,623                  |
| Q8     | CHANNEL   | 29           | 117,309                | 1.2       | 143,023                  |
|        | MARSH     | 682          | 2,760,700              | 0.14      | 387,072                  |
| Q9     | CHANNEL   | 5            | 18,996                 | 1.2       | 23,160                   |
|        | MARSH     | 457          | 1,849,307              | 0.21      | 394,568                  |
| Q10    | CHANNEL   | 13           | 53,515                 | 1.2       | 65,245                   |
|        | MARSH     | 409          | 1,656,197              | 0.22      | 363,462                  |

The inclusion of the marsh areas is critical to enhancing the model's performance. The EFDC model was having difficulties simulating flows on the Little Back and Middle Rivers and we confirmed that it was due to the marsh approach. Our first marsh approach was to calculate a tidal prism based on the simulated water surface elevations in the river compared to the bottom elevation of the marsh. We developed modifications to the EFDC codes for equations used for flow, salinity, and temperature and we intended to implement these modifications after we proved they were working. Preliminary results indicate that flows on the Little Back and Middle Rivers appeared to reflect with one another and produce flows that were out of phase with the data. We tested different sized marsh areas, but did not see improved results. Therefore, we decided to abandon our marsh approach (code modifications) and use a function that was already in the EFDC code. The revised marsh approach entails having a marsh cell connected to the model grid through a hydraulic structure. There were 17 marsh areas added to the enhanced grid and they are listed in Table 4-3 and shown in Figure 4-10. The structure requires an invert elevation and a flow table. The structure was needed to retain a water depth in the marsh cells so they did not go dry and better define the flow exchange between the marsh and the channel. The marsh cell is similar to any other model cell and requires a bottom roughness and elevation. The hydraulic structure simply allows the water to move between the river and the marsh based on the water surface elevation difference. The hydraulic structures were calibrated by modifying the marsh areas and invert elevations of the structure. Table 4-3 below shows the marsh cell connections, dimensions, bottom elevations, and structure inverts. The Q-zones reported by ATM's "Tidal Marsh Studies Data Report" Volumes 1 and 3 (2003) were still used to determine the marsh areas. Since the marsh areas do not flood on every tidal cycle, the areas were adjusted down as shown in Table 4-3. Additional marsh cells were included to represent Union Creek, Upper Little Back River, and Augustine Creek, which were not included in the Q-zones. Union Creek was put in as a storage cell without a structure.

Table 4-3 Marsh Grid Cell Parameters used in the EFDC Model

| River Cell |     | Marsh Cell |     | Marsh Dimensions        |                       | Bottom Elevations |                            | Q-zone      |
|------------|-----|------------|-----|-------------------------|-----------------------|-------------------|----------------------------|-------------|
| I          | J   | I          | J   | Calculated Size (m x m) | Adjusted Size (m x m) | Marsh (m, NGVD)   | Structure Invert (m, NGVD) |             |
| 23         | 133 | 23         | 134 | 1000                    | 1000                  | -0.7              | no structure               | Union Creek |
| 28         | 123 | 28         | 125 | 1000                    | 1000                  | -0.6              | -0.5                       | Upper LBR   |
| 33         | 123 | 33         | 125 | 1000                    | 800                   | -0.6              | -0.5                       | Upper LBR   |
| 39         | 122 | 41         | 122 | 1000                    | 300                   | -0.6              | -0.5                       | Q8          |
| 39         | 113 | 41         | 113 | 1300                    | 300                   | -0.6              | -0.5                       | Q8          |
| 30         | 92  | 32         | 92  | 1183                    | 400                   | -0.6              | -0.5                       | Q4          |
| 30         | 87  | 32         | 87  | 1354                    | 400                   | -0.6              | -0.5                       | Q3          |
| 36         | 68  | 38         | 68  | 1354                    | 400                   | -0.6              | -0.5                       | Q3          |
| 31         | 76  | 33         | 76  | 1354                    | 600                   | -0.6              | -0.5                       | Q3          |
| 26         | 95  | 28         | 95  | 922                     | 600                   | -0.6              | -0.5                       | Q5          |
| 22         | 108 | 24         | 108 | 1110                    | 600                   | 0.2               | 0.3                        | Q6          |
| 26         | 110 | 28         | 110 | 1110                    | 400                   | 0.2               | 0.3                        | Q6          |
| 26         | 116 | 28         | 116 | 1110                    | 400                   | 0.2               | 0.3                        | Q9          |
| 36         | 66  | 38         | 66  | 2846                    | 400                   | -0.6              | -0.5                       | Q2          |
| 13         | 104 | 11         | 104 | 1378                    | 600                   | -0.6              | -0.5                       | Q1          |
| 15         | 86  | 17         | 86  | 1000                    | 600                   | -0.6              | -0.5                       | Q7          |
| 13         | 96  | 11         | 96  | 2000                    | 600                   | -0.6              | -0.5                       | Augustine   |

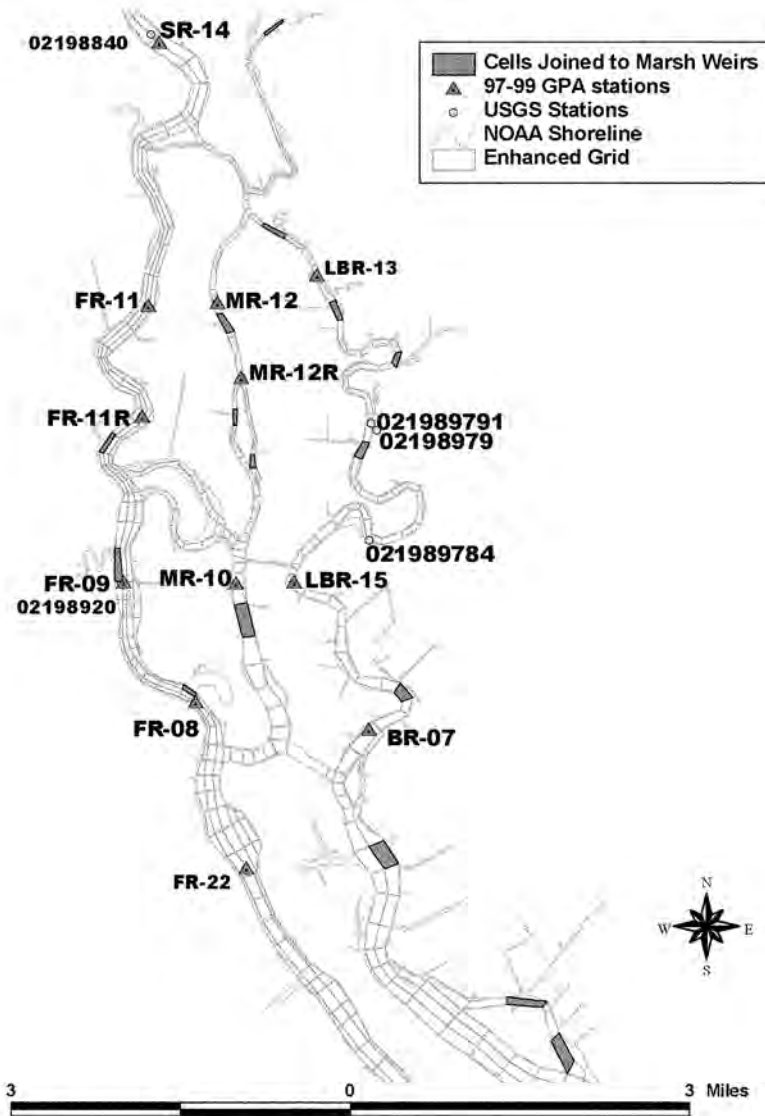


Figure 4-10 Marsh Locations in the Enhanced Model Grid (Lower Back River marsh not shown on this map)

There were several advantages to the revised marsh approach. First, our flow calibration was much improved and the simulated flows were smoother similar to the rising and falling tides. Second, there were no changes to the EFDC code necessary, since the hydraulic structures have always been in the EFDC code. Third, the salinity calibration was much improved in the Little Back and Middle Rivers, as we now see the elevated levels of salinity at those stations. Fourth, we did not have to use the wetting and drying options in EFDC that would significantly lower our model time step and increase the model run times.

The flow through the structure was calculated based on the Manning equation described below:

$$Q = \frac{1}{n} AR^{2/3} F^{1/2}$$

$$R = A / P$$

where  $n$  is a Manning roughness;  $R$  is a hydraulic radius;  $P$  is a wetted perimeter;  $F$  is the energy slope.

$F$  can be approximated by a water surface elevation slope:

$$F = \frac{\Delta H}{L_x}$$

where  $\Delta H$  is a water surface elevation difference between the marsh cell and the channel cell. The EFDC weir formulation uses a look-up table of  $\Delta H$  versus flow ( $Q$ ). The look-up tables were computed based on the information in Table 4-3.

#### 4.4.4 Meteorological

The meteorological forcing conditions are input into the EFDC model through the "user.inp" file. This file contains the following:

- Barometric pressure,
- Dry bulb temperature,
- Relative humidity,
- Rainfall,
- Evaporation,
- Solar Radiation, and
- Cloud Cover.

Most of the parameters came from the Savannah Airport historical data record. The airport is located roughly 4 miles from the estuary and represents the best source of meteorological data for the estuary. Barometric pressure, temperature, relative humidity, rainfall, and cloud cover were all measured at the airport. Evaporation and solar radiation were calculated and put into the model. Although meteorological data were collected during 1997 and 1999, the EFDC model was setup for seven years so a consistent record was created. The "user.inp" file was developed on an hourly basis. Figure 4-11 shows the air temperature and rainfall for the period.

The wind data in the "wser.inp" file were also developed on an hourly basis and also collected at the Savannah Airport.

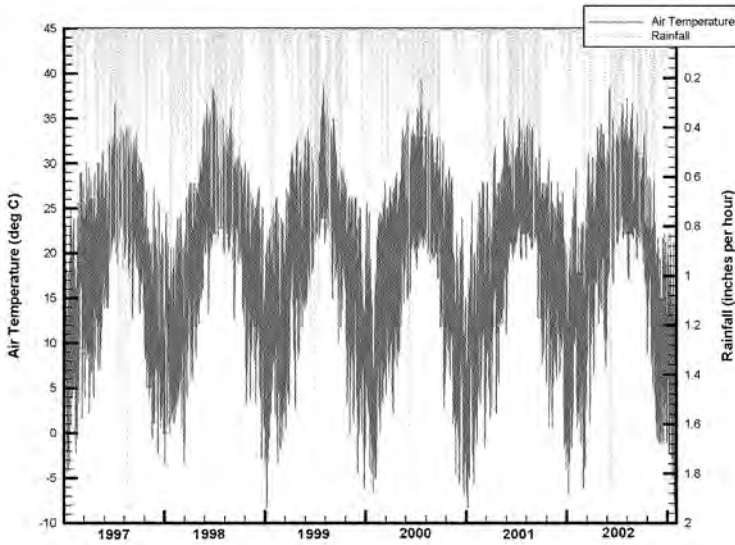


Figure 4-11 Air Temperature and Rainfall in Meteorological Forcing



#### 4.4.5 Point Sources Flow and Heat Loads

The Savannah Hydrodynamic Model includes major point sources/sinks discharges and withdrawals. The corresponding information was presented to Tetra Tech Inc. by partnering federal, state and local agencies. Some of these discharges/withdrawals were presented as annual averages, and for some of them the time series measurements were available. The averaged discharges/withdrawals are presented in Table 4-4; time series discharges/withdrawals are referred in Table 4-5.

Table 4-4 Annually Averaged Point Sources Discharges/Withdrawals for Savannah River Model

| Point Source Discharge/Withdrawal            | Location Cell (I, J) | Flow (m <sup>3</sup> /s) |
|----------------------------------------------|----------------------|--------------------------|
| Smurfit discharge                            | I=13, J=95           | 0.113906                 |
| Garden City discharge                        | I=13, J=77           | 0.049943                 |
| Whilshire discharge                          | I=13, J=74           | 0.135811                 |
| Travis Field discharge                       | I=13, J=74           | 0.033296                 |
| President Street discharge                   | I=13, J=54           | 0.823628                 |
| Englehard discharge                          | I=13, J=52           | 0.042496                 |
| Kerr McGee #1 discharge                      | I=13, J=48           | 0.56953                  |
| Kerr McGee #2 discharge                      | I=13, J=48           | 0.122668                 |
| Savannah Electric Plant Macintosh discharge  | I=14, J=172          | 5.7                      |
| Savannah Electric Port Wentworth discharge   | I=13, J=85           | 11.3                     |
| Savannah Electric Plant Macintosh withdrawal | I=14, J=173          | -5.7                     |
| Savannah Electric Port Wentworth withdrawal  | I=13, J=84           | -11.3                    |
| Riverside Power Plant discharge              | I=13, J=57           | 2.13                     |
| Riverside Power Plant withdrawal             | I=13, J=58           | -2.13                    |

Table 4-5 Time Series Discharges/Withdrawals for Savannah River Model

| Point Source Discharge/Withdrawal                      | Location Cell (I, J) | Flow (m <sup>3</sup> /s) |
|--------------------------------------------------------|----------------------|--------------------------|
| Hardeeville discharge                                  | I=14, J=148          | Time Series              |
| Fort James discharge                                   | I=14, J=171          | Time Series              |
| Savannah Industrial & Domestic Water Supply withdrawal | I=8, J=130           | Time Series              |
| Beaufort-Jasper Water Authority withdrawal             | I=14, J=163          | Time Series              |
| International Paper discharge                          | I=15, J=70           | Time Series              |

Estimates of potential freshwater flow from watersheds (based on values of their areas) surrounding the Savannah River from Clio down to Savannah Harbor support increasing the upstream boundary freshwater river flow by 10% and including two additional sources of freshwater flow at: Union Creek (I=21, J=59) – 5m<sup>3</sup>/s, and Front River (I=5, J=52) – 10m<sup>3</sup>/s.

Heat loads from three power plants: Savannah Electric Plant Macintosh, Savannah Electric Port Wentworth and Riverside Power Plant were calculated based on estimates of their discharges by pump capacities for river water withdrawal, and capacities of power generation.

The “heat rate” for coal-fired steam-electric power plants is about 10,000 BTU heat input per Kw-hr of electricity generated (about 34% efficient). One Kw-hr is equivalent to 3413 BTU. Therefore, generating one Kw-hr of electricity results in a heat load of 6387 BTU (10,000 – 3413) that must be rejected to the environment. Assuming 95% of this heat is rejected to the river (with the other 5% going directly to the local atmosphere), one Kw-hr of generated electricity results in a heat load of about 6300 BTU to the river. One BTU raises the temperature of one pound of water one degree Fahrenheit.

Based on these assumptions and available data we can calculate increasing of temperature in discharged power plants’ waters by following formula:

$$\Delta^{\circ}C = P * 6300 * a * Q^{-1} * b$$

where  $\Delta^{\circ}C$  is a increasing of temperature of discharged waters (degree of Celsius); P is a power generation (Kw-hr);  $a=0.55$  is a conversion coefficient of temperature change from Fahrenheit to Celsius; Q is a power plant discharge (m<sup>3</sup>/hr);  $b=0.0004536$  is a conversion coefficient from a pound to a metric ton. We did not have detailed information about power generation of the Riverside Power Plant. The temperature increase was assumed to equal the increase of the Savannah Electric Port Wentworth plant.

Table 4-6 Heat Loads for Savannah River Model

| Power Plant                       | Power Generation (Kw-Hr) | Water Discharge (m <sup>3</sup> /s) | Heat Load (BTU)       |
|-----------------------------------|--------------------------|-------------------------------------|-----------------------|
| Savannah Electric Plant Macintosh | 800,000                  | 5.70                                | 5.040*10 <sup>9</sup> |
| Savannah Electric Port Wentworth  | 160,000                  | 11.27                               | 1.008*10 <sup>9</sup> |
| Riverside Power Plant             | 30,240                   | 2.13                                | 1.906*10 <sup>8</sup> |

The temperature of discharged waters of power plants was assumed to be the sum of Clio water temperature time series plus . These new calculated time series were placed into TSER.INP file and use to determine the heat load of the Savannah power plants and results are shown in Table 4-6.

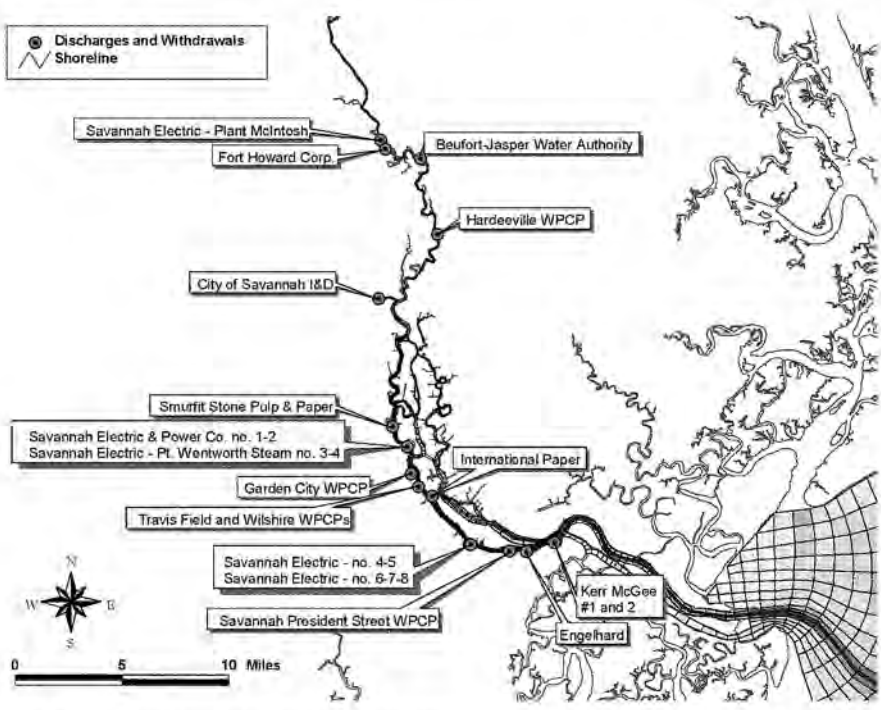


Figure 4-12 Point Source Discharges and Withdrawals in the Savannah River Estuary

## 5.0 EFDC CALIBRATION

The calibration methodology for the Savannah Harbor EFDC model included graphical time series comparisons (qualitative) and statistical calculations (quantitative). The statistical calculations included a variety of statistical calculations including percentiles for every 5<sup>th</sup> percentile interval. The calibration methodology was also parameter specific starting with the following order:

- Water Surface Elevation,
- Currents,
- Flow,
- Temperature, and
- Salinity.

Each one of these parameters has its importance in the determination of success for the model calibration and confirmation. The order in which the hydrodynamic model is calibrated is performed to address issues such as bathymetry, friction, tidal volume, cross-sectional area, and heat budget before salinity is calibrated. Salinity is the predominant signal in the model to ensure that mass is being moved horizontally and vertically with the appropriate timing and direction.

The calibration objectives for the hydrodynamic model were to appropriately represent the transport processes by propagating momentum and energy through the system based upon freshwater inflow from the Savannah River and tidal energy from the Atlantic Ocean. Since vertical stratification plays a major role in the water quality of the lower harbor area, it was imperative to capture the effect of tides and fresh water flows on salinity and temperature over the appropriate spatial and temporal scales. The primary objective was to simulate the salinity and temperature stratification events, and to demonstrate that the duration and magnitude of the events were appropriately represented in the model. The next three sections will describe the qualitative and quantitative calibration techniques along with reporting requirements of the federal agencies.

### 5.1 Comparisons

Time series graphical comparisons were performed to visualize key trends in the data compared to that of the model. Seasonal fluctuations of temperature, salinity stratification, ebb current magnitudes versus flood, and spring/neap tidal fluctuations were all compared to the physical data to determine if the model is simulating appropriately.

MOVEM was used to open the EFDC model output files (\*.BMD) and the WRDB data files (\*.DB) for the graphical comparisons. Other than the ADCP flow transects compared in Tecplot files, all other time series graphics in this report were generated by MOVEM. MOVEM allows the user to window in on various time periods so that a closer examination of the model versus data can be performed.

MOVEM was also used to animate the model results. There are three main files included on the discs that will allow the user to visualize the EFDC model results. The "EFDC\_OUT.BMD" is included for the 1999 calibration period and contains every cell in the grid domain. The "fixed\_grid8" shape files are also included which allows the model to be viewed in a plan view in MOVEM and links each of the grid cells to the model output. Also, the "shoreline.shp" file can be brought in as a shoreline boundary for a frame of reference.

## 5.2 Quantitative Comparisons

A variety of model fit statistics are available for evaluating model performance (Reckhow et al., 1990). Since MOVEM was used to perform the qualitative component of the calibration, MOVEM was also updated to perform the quantitative calculations. For the statistical evaluations, the following calculations were generated along with the percentiles.

Mean Error:  $ME = \bar{P} - \bar{O}$

Mean Error Absolute:  $MEA = \frac{\sum_{i=1}^n |P_i - O_i|}{n}$

Mean Error Percent:  $MEP = \frac{MEA}{\bar{O}} \times 100$

RMS Error:  $RMSEA = \sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}}$

RMS Error Percent:  $RMSEP = \frac{RMSEA}{\bar{O}} \times 100$

Mean Predicted:  $\bar{P} = \frac{\sum_{i=1}^n P_i}{n}$

Standard Deviation Predicted:  $SDP = \sqrt{\frac{\left(n \sum_{i=1}^n P_i^2\right) - \left(\sum_{i=1}^n P_i\right)^2}{n^2}}$

Mean Observed:  $\bar{O} = \frac{\sum_{i=1}^n O_i}{n}$

Standard Deviation Observed:  $SDO = \sqrt{\frac{\left(n \sum_{i=1}^n O_i^2\right) - \left(\sum_{i=1}^n O_i\right)^2}{n^2}}$

$$R^2 = \frac{\left( n \sum_{i=1}^n (P_i \times O_i) \right) - \left( \sum_{i=1}^n O_i \times \sum_{i=1}^n P_i \right)}{\sqrt{\left( \left( n \sum_{i=1}^n P_i^2 \right) - \left( \sum_{i=1}^n P_i \right)^2 \right)} \times \sqrt{\left( \left( n \sum_{i=1}^n O_i^2 \right) - \left( \sum_{i=1}^n O_i \right)^2 \right)}}$$

$$\text{Coefficient of efficiency, } E = 1.0 - \frac{\sum_{i=1}^n |P_i - O_i|}{\sum_{i=1}^n |O_i - \bar{O}|}$$

$$\text{Index of agreement, } d = 1.0 - \frac{\sum_{i=1}^n |P_i - O_i|}{\sum_{i=1}^n (|P_i - \bar{O}| + |O_i - \bar{O}|)}$$

The correlation coefficient,  $R^2$ , measures the tendency of the predicted and observed values to vary together linearly. It can range from -1 to 1, with negative values indicating that the observed and predicted values tend to vary inversely. It should be recognized that even if the correlation is close to 1, the predicted and observed values might not match each other; they only tend to vary similarly (Stow, 2003).

The root mean squared error, average error, and average absolute error are all measures of the size of the discrepancies between predicted and observed values. Values near zero indicate a close match. The average error is a measure of aggregate model bias, though values near zero can be misleading because negative and positive discrepancies can cancel each other. The average absolute error and the root mean squared error both accommodate the shortcoming of the average error by considering the magnitude rather than the direction of each discrepancy. Together these three statistics provide an indication of model prediction accuracy (Stow, 2003).

The coefficient of efficiency,  $E$ , ranges from minus infinity to 1.0, with higher values indicating better agreements. The modeling efficiency measures how well a model predicts relative to the average of the observations. A value near one indicates a close match between observations and model predictions. A value of zero indicates that the model predicts individual observations no better than the average of the observations.

### 5.3 Federal Expectations

In 2001, the Federal agencies prepared a Draft Expectations Document that described (1) the resources of primary concern in the estuary, (2) the locations and conditions under which project impacts should be evaluated for those resources, (3) the modeling approach to be taken, (4) the statistical analyses to be performed to document the model's performance, and (5) the evaluation criteria (Federal Agencies, 2003).

The Expectations Document stated that its listed criteria were to be viewed as performance goals to which model predictions would be compared and evaluated for strengths and weaknesses and by which an understanding of their uncertainties may be developed. The stated criteria would not be used individually (by station and parameter) for a "pass/fail" evaluation of the model calibration and/or any post-processing routine.

The Document also stated that statistical analysis were to include calculation of the mean error, root mean square error, absolute mean error and relative error. Additionally, comparisons of selected percentiles are to be used to evaluate model performance. The statistical analyses are to be performed on both the 1997 and 1999 data sets. For the 1997 validation data set, analyses are to be performed on each of the six spring/neap tidal cycles between July 9, 1997 and Oct 5, 1997. The Julian dates for those six periods are: 191-204, 205-219, 220-234, 235-249, 250-263, 264-279. For the 1999 calibration data set, analyses are to be performed on each of the five spring/neap tidal cycles between July 31 and October 13, 1999. The Julian dates for the five periods are: 213-226, 227-241, 242-255, 256-270, and 271-285.

Table 5-1 Federal Expectations for Hydrodynamic and Water Quality Model Calibration/Confirmation

| Parameter                 |             | Percentiles |         |         |         |         | Timing of Maxima (Min) |
|---------------------------|-------------|-------------|---------|---------|---------|---------|------------------------|
|                           |             | 5 %         | 10 %    | 50 %    | 90 %    | 95 %    |                        |
| Elevation (cm)            |             | +/- 2       | -       | +/- 2   | -       | +/- 2   | +/- 30                 |
| Salinity (ppt)            | 50% > 5 ppt | -           | +/- 10% | -       | +/- 10% | -       | +/- 30                 |
|                           | 50% < 5 ppt | -           | -       | +/- 0.5 | +/- 0.5 | -       | +/- 30                 |
| DO (mg/L)                 |             | -           | +/- 0.2 | +/- 0.2 | -       | -       | +/- 30                 |
| DO Deficit (mg/L)         |             | -           | +/- 0.2 | +/- 0.2 | -       | -       | +/- 30                 |
| Temperature (°C) *        |             | -           | -       | +/- 1   | -       | -       | -                      |
| Surface Currents (m/s) ** |             | +/- 25%     | -       | -       | -       | +/- 25% | +/- 30                 |
| Volume Flows (m/s) **     |             | +/- 25%     | -       | -       | -       | +/- 25% | -                      |

\* 50% represent Absolute Mean Error for temperature

\*\* 5% and 95% represent the max. ebb and flood conditions for current and flow

The model calibration results are presented in this section and in several appendices to this report. As stated previously, the model calibration was performed from the qualitative comparisons, quantitative comparisons, and the federal agency expectations comparisons. The calibration period was the summer of 1999 and the confirmation period was the summer of 1997. The longterm USGS data will also be used for confirmation. The two summer periods were both low-flow conditions with several spring/neap tide events occurring throughout the period.

The EFDC locations where data comparisons were made is shown in Table 5-2. The I and J locations are used to plot the time series comparisons in MOVEM and calculate statistics.

Table 5-2 EFDC I and J Locations of Data Stations

| Station ID    | Description                               | River Mile | I  | J   |
|---------------|-------------------------------------------|------------|----|-----|
| GPA Stations  |                                           |            |    |     |
| FR-26         | Front River at Fort Pulaski               | 0.8        | 14 | 23  |
| FR-02         | Front River in the Entrance Channel       | 4.5        | 14 | 30  |
| SC-03         | South Channel                             | 5.5        | 10 | 28  |
| FR-04         | Front River near Fort Jackson             | 10.4       | 14 | 48  |
| FR-21         | Front River at USACE Depot                | 13.9       | 14 | 57  |
| BR-05         | Back River at Hwy 17                      | 14.5       | 31 | 66  |
| FR-06         | Front River upstream of Houlihan Bridge   | 16.6       | 14 | 63  |
| FR-22         | Front River at Kings Island Turning Basin | 18.7       | 14 | 76  |
| BR-07         | Back River                                | 18.9       | 30 | 84  |
| FR-08         | Front River                               | 20.5       | 14 | 85  |
| LBR-15        | Little Back River at Houlihan Bridge      | 20.9       | 30 | 96  |
| FR-09         | Front River at Houlihan Bridge            | 21.5       | 14 | 95  |
| MR-10         | Middle River at Houlihan Bridge           | 21.8       | 26 | 96  |
| FR-11         | Front River                               | 24.7       | 14 | 113 |
| FR-11R        | Front River, Revised 1999                 | 23.4       | 14 | 106 |
| MR-12         | Middle River                              | 24.4       | 26 | 117 |
| MR-12R        | Middle River, Revised 1999                | 23.7       | 26 | 113 |
| LBR-13        | Little Back River                         | 26.6       | 31 | 123 |
| SR-14         | Savannah River at I-95 Bridge             | 27.7       | 14 | 126 |
| SR-16         | Savannah River near Hardeeville           |            | 14 | 137 |
| SR-17         | Savannah River near Ebenezer Creek        |            | 14 | 173 |
| USGS Stations |                                           |            |    |     |
| 02198980      | Front River at Fort Pulaski               | 0.8        | 13 | 23  |
| 02198977      | Front River at Broad Street               | 14.6       | 13 | 59  |
| 02198920      | Front River at Houlihan Bridge            | 21.5       | 14 | 95  |
| 021989791     | Little Back River at USF&W Dock           | 22.1       | 30 | 106 |
| 02198979      | Little Back River at Limehouse Cr         | 24.1       | 39 | 114 |
| 021989784     | Little Back River at Lucknow Canal        | 24.2       | 39 | 114 |
| 02198840      | Savannah River at I-95 Bridge             | 27.7       | 14 | 127 |
| 02198500      | Savannah River near Clyo, GA              | 61         | 14 | 213 |



## 5.4 Water Surface Elevation Calibration

The water surface calibration was performed by modifying the downstream elevation boundary until the model closely fit the data at Fort Pulaski. Then for the internal gages in the harbor, the bottom roughness was modified to reach an appropriate phase shift of the elevation signal at each one of the stations. Bottom roughness is the key parameter in addition to bathymetry to calibrate water surface elevation. Currently, the EFDC model uses 0.03 as a global bottom roughness with no adjustments spatially. This value can be found in the "efdc.inp" file and the spatial adjustments in the "dxdy.inp" file.

The summary statistics and time series plots of the draft calibration for water surface elevation are shown in Appendix B. The Federal Expectations require reporting of the 10<sup>th</sup>, 50<sup>th</sup>, and 90<sup>th</sup> percentiles of the model compared with the data. Table B-1 shows the percentiles for the entire 1999 summer period and Table B-2 shows the summary statistics. The five spring/neap events are plotted and summarized in Tables B-3 through B-12.

The 1999 water surface elevation was also compared using a harmonic analysis. The harmonic analysis calculates the main tidal components (M2, S2, N2, K1, O1) from the time series of measurements and simulated results. The results are presented in Table 5-3.

## 5.5 Currents Calibration

The summary statistics and time series plots of the draft calibration for currents are shown in Appendix D. The Federal Expectations require reporting of the 5<sup>th</sup>, 50<sup>th</sup>, and 95<sup>th</sup> percentiles of the model compared with the data. The EFDC model performs very well on the currents in magnitude and phasing at FR-04 and -06 for 1999 for the surface stations. The Federal Expectations are met for the surface data.

The stations upstream of I-95 Bridge where the AquaDopp Current meters were deployed could not be compared to a "Surface Current" as pointed out in the Federal Expectations document. Therefore, these stations were not considered in the statistical comparisons with the model.

## 5.6 Flow Calibration

The flow calibration was performed on the ADCP transect data collected in 1999. The transect locations are not shown in a figure but the transect times are located in Appendix F in Table F-1 and results are shown for F-2. There were 15 transects in 1997 and 42 transects in 1999.

The summary statistics and time series plots of the draft calibration for flows are shown in Appendix F. The Federal Expectations require reporting of the peak ebb and the peak flood of the model compared with the data. The EFDC model performs very well on the flows overall but under predicts the ebb flows in the Front and Back Rivers.

## 5.7 Temperature Calibration

Temperature was the hydrodynamic parameter with the least calibration. The temperature data were used at Clio and then a seasonal temperature function was used for the downstream boundary. The summary statistics and time series plots of the draft calibration for temperature are shown in Appendix H with the summary of results in Tables H-1 and H-2. The Federal Expectations require reporting of the 50<sup>th</sup> percentiles of the model compared with the data. The EFDC model performs very well on the temperature and meets all of the Federal Expectations for the Absolute Mean Error at every site.

Table 5-3 Comparison of Observed and Model Predicted Tidal Harmonic Constituents

| Station  | Harm | AmpObs (m) | AmpMod (m) | Amp Error (m) | Amp Relative Error (%) | PhsObs (hr) | PhsMod (hr) | Phs Error (hr) | Phs Error (degrees) |
|----------|------|------------|------------|---------------|------------------------|-------------|-------------|----------------|---------------------|
| FR-26    | M2   | 1.034      | 1.026      | 0.008         | 0.8                    | 6.14        | 6.25        | -0.11          | -3.19               |
|          | S2   | 0.158      | 0.147      | 0.011         | 7.0                    | 8.81        | 8.89        | -0.08          | -2.40               |
|          | N2   | 0.169      | 0.176      | -0.007        | 4.1                    | 6.79        | 6.80        | -0.01          | -0.28               |
|          | K1   | 0.094      | 0.094      | 0.000         | 0.0                    | 9.32        | 9.48        | -0.16          | -2.41               |
|          | O1   | 0.071      | 0.075      | -0.004        | 5.6                    | 4.88        | 5.49        | -0.61          | -8.51               |
| FR-04    | M2   | 1.134      | 1.149      | -0.015        | 1.3                    | 6.50        | 6.59        | -0.09          | -2.61               |
|          | S2   | 0.176      | 0.168      | 0.008         | 4.5                    | 9.20        | 9.43        | -0.23          | -6.90               |
|          | N2   | 0.198      | 0.195      | 0.003         | 1.5                    | 7.25        | 7.26        | -0.01          | -0.28               |
|          | K1   | 0.098      | 0.100      | -0.002        | 2.0                    | 9.95        | 9.74        | 0.21           | 3.16                |
|          | O1   | 0.083      | 0.073      | 0.010         | 12.0                   | 5.41        | 5.69        | -0.28          | -3.90               |
| FR-06    | M2   | 1.178      | 1.219      | -0.041        | 3.5                    | 6.70        | 6.72        | -0.02          | -0.58               |
|          | S2   | 0.153      | 0.160      | -0.007        | 4.6                    | 9.31        | 9.44        | -0.13          | -3.90               |
|          | N2   | 0.178      | 0.177      | 0.001         | 0.6                    | 7.68        | 7.65        | 0.03           | 0.85                |
|          | K1   | 0.088      | 0.090      | -0.002        | 2.3                    | 10.13       | 9.95        | 0.18           | 2.71                |
|          | O1   | 0.090      | 0.078      | 0.012         | 13.3                   | 5.12        | 5.67        | -0.55          | -7.67               |
| FR-08    | M2   | 1.198      | 1.255      | -0.057        | 4.8                    | 6.82        | 6.78        | 0.04           | 1.16                |
|          | S2   | 0.167      | 0.178      | -0.011        | 6.6                    | 9.62        | 9.68        | -0.06          | -1.80               |
|          | N2   | 0.199      | 0.204      | -0.005        | 2.5                    | 7.56        | 7.48        | 0.08           | 2.28                |
|          | K1   | 0.100      | 0.103      | -0.003        | 3.0                    | 10.17       | 9.93        | 0.24           | 3.61                |
|          | O1   | 0.083      | 0.072      | 0.011         | 13.3                   | 5.70        | 5.95        | -0.25          | -3.49               |
| FR-09    | M2   | 1.195      | 1.243      | -0.048        | 4.0                    | 6.85        | 6.87        | -0.02          | -0.58               |
|          | S2   | 0.168      | 0.173      | -0.005        | 3.0                    | 9.65        | 9.81        | -0.16          | -4.80               |
|          | N2   | 0.203      | 0.202      | 0.001         | 0.5                    | 7.62        | 7.61        | 0.01           | 0.28                |
|          | K1   | 0.102      | 0.102      | 0.000         | 0.0                    | 10.20       | 10.08       | 0.12           | 1.80                |
|          | O1   | 0.083      | 0.073      | 0.010         | 12.0                   | 5.95        | 6.04        | -0.09          | -1.25               |
| SR-14    | M2   | 0.975      | 1.174      | -0.199        | 20.4                   | 7.67        | 7.23        | 0.44           | 12.75               |
|          | S2   | 0.089      | 0.137      | -0.048        | 53.9                   | 10.15       | 10.25       | -0.10          | -3.00               |
|          | N2   | 0.096      | 0.163      | -0.067        | 69.8                   | 9.70        | 8.32        | 1.38           | 39.25               |
|          | K1   | 0.098      | 0.090      | 0.008         | 8.2                    | 12.54       | 10.43       | 2.11           | 31.74               |
|          | O1   | 0.097      | 0.076      | 0.021         | 21.6                   | 7.40        | 6.18        | 1.22           | 17.01               |
| 02198979 | M2   | 1.079      | 1.022      | 0.057         | 5.3                    | 7.51        | 7.47        | 0.04           | 1.16                |
|          | S2   | 0.128      | 0.133      | -0.005        | 3.9                    | 11.01       | 10.66       | 0.35           | 10.50               |
|          | N2   | 0.179      | 0.163      | 0.016         | 8.9                    | 8.74        | 8.26        | 0.48           | 13.65               |
|          | K1   | 0.127      | 0.096      | 0.031         | 24.4                   | 11.66       | 10.56       | 1.10           | 16.55               |
|          | O1   | 0.109      | 0.070      | 0.039         | 35.8                   | 7.91        | 6.55        | 1.36           | 18.96               |

## 5.8 Salinity Calibration

Salinity is the key parameter of concern because it can dictate how well the model is transporting mass in the system. For the summer-fall periods of 1997 and 1999, there is an extensive amount of salinity data from the system, including surface and bottom instruments in the navigation channel. Therefore, it was important to perform a rigorous calibration meanwhile keeping in mind that the model could be used over longer time periods. Also, that the model will be used in a predictive mode to simulate a management scenario for the harbor.

The summary statistics and time series plots of the draft calibration for salinity are shown in Appendix J. The Federal Expectations require reporting of the 10<sup>th</sup>, 50<sup>th</sup>, and 90<sup>th</sup> percentiles of the model compared with the data. The EFDC model performs very well in the navigation channel and demonstrates the stratifying and de-stratifying process at stations FR-04, -21, -06, -22, -08, and -09 (main Front River stations).

The criteria were established for the stations: GPA 5, 6, 7, 8, 9, 10, 11R, 12R, 15, and 22 and five USGS stations. The July 31-October 13 (Appendix J) calibration results show that the model met the criteria for USGS stations 80% (4/5) and for GPA stations 21% (3/14) for 10th percentile and 29% (4/14) for 90th percentile. Correlation of simulations and observations was meaningful ( $>0.6$ ) for 80% of USGS stations and 79% (11/14) of GPA stations. The difference in meeting criteria for USGS and GPA sites can be explained partly by quality and duration of compared data. The average duration of data for USGS stations is 100% of the simulated period of time, and only 50-70% for GPA stations due to data gaps. This explains some problematic aspects of comparing percentiles of simulation results with incomplete data.

The EFDC calibration for 1999 has been enhanced over the TMDL version of the model. Once again, we went back through the bathymetry data to confirm the deepest point of the cross-section to verify the model depths for the channel. Also, the revised marsh approach increased the tidal prism, or amount of water moving into and out of the harbor on a tidal cycle, which has improved the mixing in the channel. The more tidal prism (spring tides), the more mixing. Table 5-4 and Figure 5-1 characterize the amount of stratification and de-stratification represented by the model. The analysis below was performed at FR-06 for a stratified and de-stratified (mixed) period in August 1999.

Table 5-4 Characterization of Stratified and Mixed Salinity Conditions

| Stratified Conditions: 8/20/99 0:00 - 8/23/99 0:00 |               |                |
|----------------------------------------------------|---------------|----------------|
|                                                    | Mean Observed | Mean Predicted |
| Bottom:                                            | 23.9          | 21.1           |
| Surface:                                           | 6.5           | 5.2            |
| Delta:                                             | 17.4          | 15.8           |
| Mixed Conditions: 8/28/99 0:00 - 8/31/99 0:00      |               |                |
|                                                    | Mean Observed | Mean Predicted |
| Bottom:                                            | 12.0          | 11.8           |
| Surface:                                           | 5.5           | 3.5            |
| Delta:                                             | 6.5           | 8.3            |

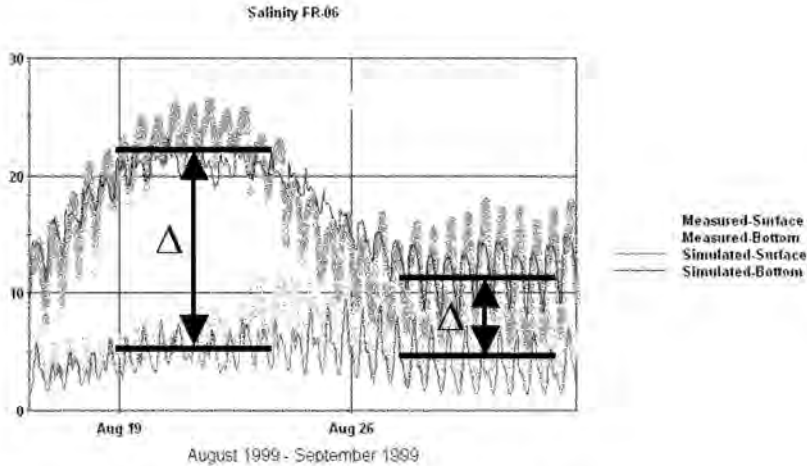


Figure 5-1 Salinity Stratification at FR-06 on the Front River

Figures 5-2 through 5-5 show the model's performance on stratifying and de-stratifying at stations FR-04, -06, -08, and -09, respectively. The EFDC model is capturing the dynamics of the salinity stratification for the navigation channel. The model still under predicts the range in salinity but this is much improved from the TMDL model.

Figures 5-6 and 5-7 show the salinity at station FR-11R, which is 2 miles upstream of the Houlihan Bridge on the Front River. This station captures the edge of the salinity wedge as it moves out of the navigation channel downstream of the Houlihan Bridge and pushes up the river. This is a critical station to compare to the model and important for demonstrating the model's abilities to identify changes expected from future deepening scenarios. Figure 5-6 shows the entire 1999 calibration period and Figure 5-7 shows a 7-day neap event in August. The salinity pumping is evident in Figure 5-7 by the steepness of the salinity signal and the salinity concentrations go from 0 to 10 back to 0 ppt in a very short period of time.

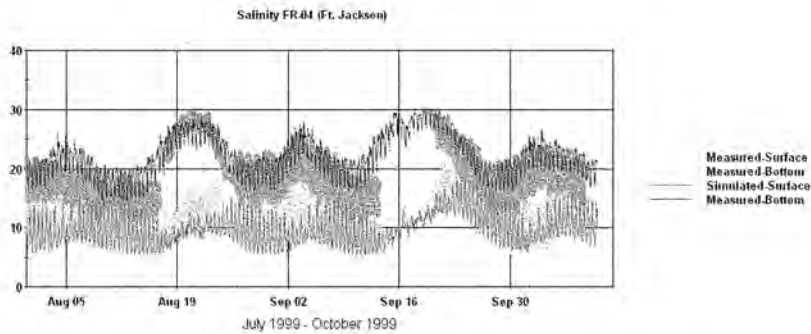


Figure 5-2 1999 Salinity on the Front River at Fort Jackson (FR-04)

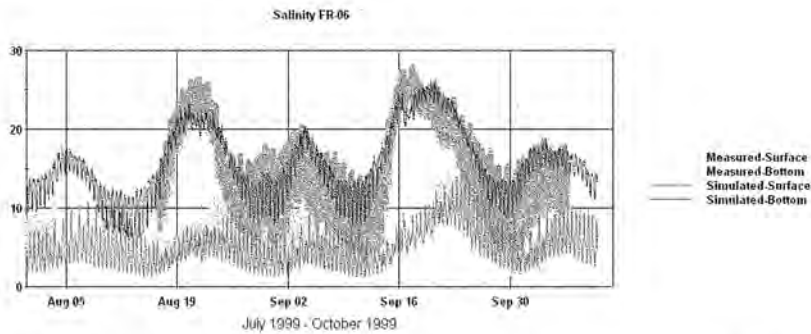


Figure 5-3 1999 Salinity on the Front River Upstream of Talmadge Bridge (FR-06)

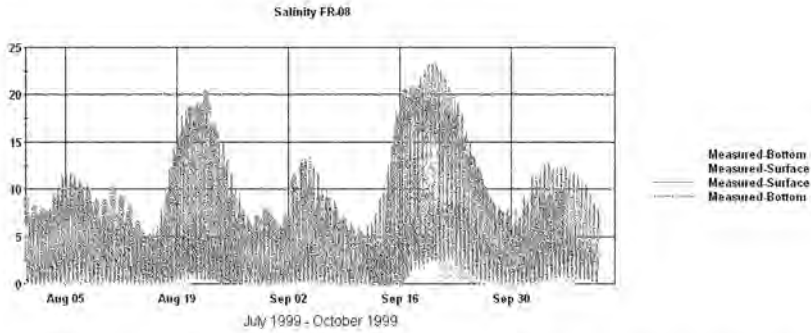


Figure 5-4 1999 Salinity on the Front River near Middle River Confluence (FR-08)

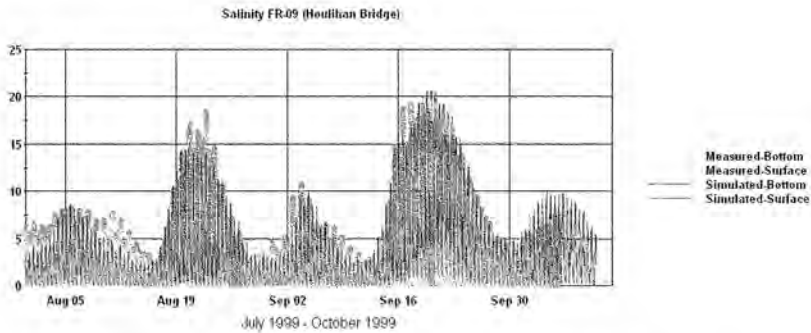


Figure 5-5 1999 Salinity on the Front River at Houlihan Bridge (FR-09)

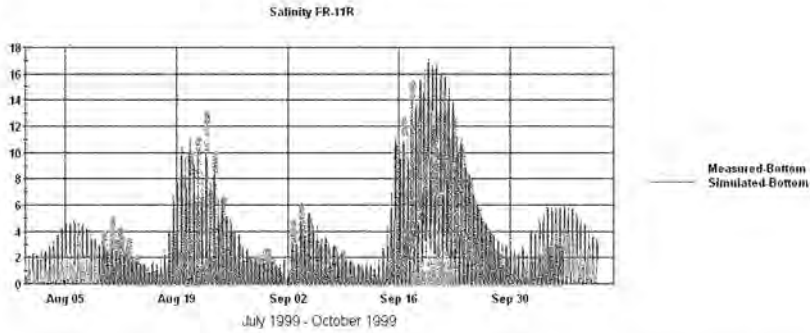


Figure 5-6 1999 Salinity on the Front River Upstream of Houlihan Bridge (FR-11R)

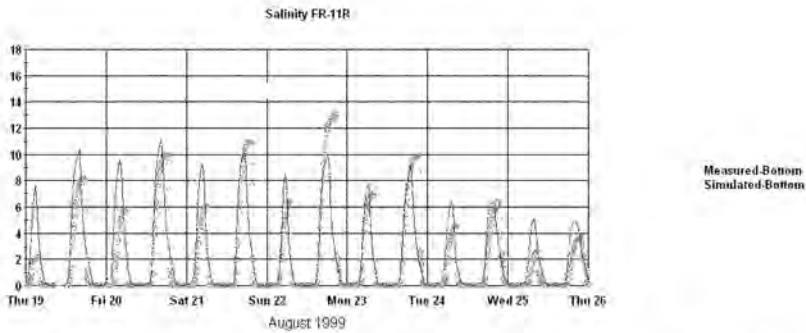


Figure 5-7 August 1999 Salinity on the Front River Upstream of Houlihan Bridge (FR-11R)

Another way to visualize the model's performance is to examine the statistics on a longitudinal plot. Figures 5-8 and 5-9 show the Front River and navigational channel stations for 1999. Figure 5-8 shows the surface comparisons and Figure 5-9 shows the bottom comparisons. The comparisons show that the EFDC model is capturing the major trends in the navigation channel. Figure 5-8 also shows that the model more accurately represents measured surface salinities in the upper harbor (where salinity is more of a concern) than in the lower harbor.

Longitudinal Distributions of Salinity for 1999 Surface Stations

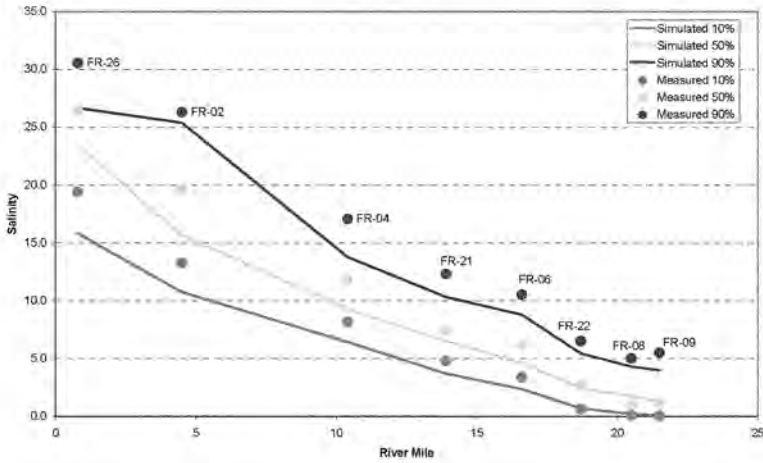


Figure 5-8 1999 Measured versus Simulated Longitudinal Surface Salinity

Longitudinal Distributions of Salinity for 1999 Bottom Stations

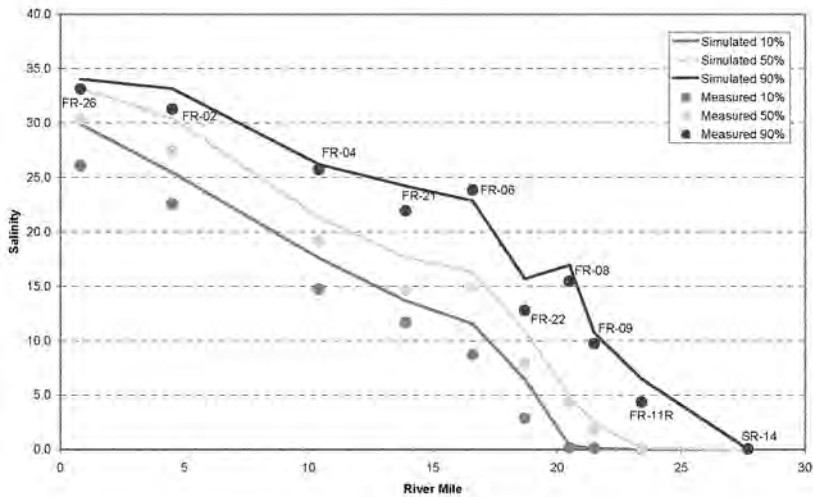


Figure 5-9 1999 Measured versus Simulated Longitudinal Bottom Salinity



## 6.0 EFDC MODEL CONFIRMATION

After the model was calibrated, the reliability of the model's predictions was tested with a new dataset. It is important that the model testing be performed with the exact same parameters used in the calibration process. The only real validation of a model is confirmation by independent observations (Anscombe, 1967). The testing of scientific models is considered an inductive process, which means that, even with true premises we can at best assign high probability to the correctness of the model. The fact that models can never be absolutely verified has significant policy implications. By admitting that models are approximations, it negates stall tactics based on the premise that remedial action be indefinitely postponed because models can never be demonstrated to be absolutely true (Chapra, 2003).

The USGS data were obtained for the periods of January 1, 1997 through December 31, 2003 to confirm the EFDC model. These data were not used to calibrate the model, but rather confirm the model's performance over the seven years. The data were imported into WRDB so that they could be available through MOVEM and statistics generated. The following sections summarize the confirmation results.

The time period for the EFDC model confirmation is the summer of 1997 from July 5, 1997 through October 13, 1997. The 1997 confirmation was performed with no changes to the boundary conditions or inputs. Figures 6-1 and 6-2 show the results of the longitudinal distributions of salinity in the navigational channel.

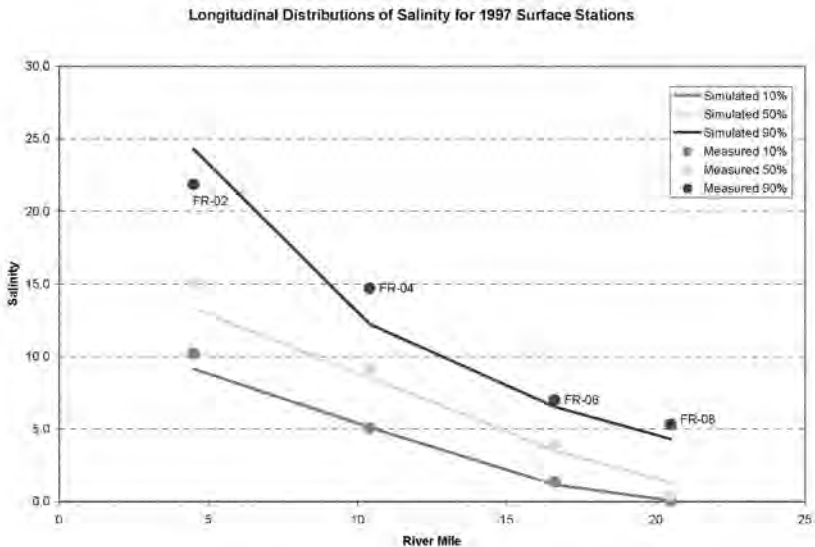


Figure 6-1 1997 Measured versus Simulated Longitudinal Surface Salinity

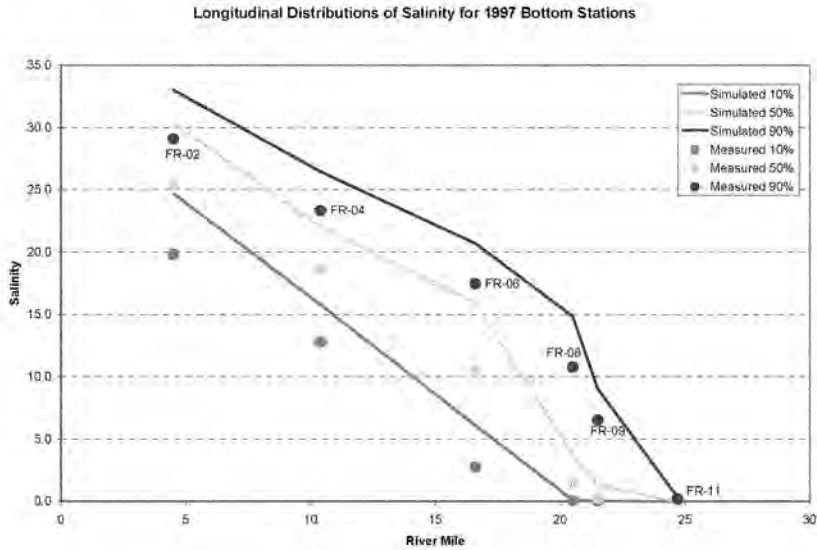


Figure 6-2 1997 Measured versus Simulated Longitudinal Bottom Salinity

Appendix C shows the water surface elevation, Appendix E shows the currents, Appendix G shows the flows, Appendix I shows the temperature, and Appendix K shows the salinity of the 1997 confirmation model run.

Appendix L shows the 1997 through 2003 water surface elevation confirmation comparisons and Appendix M shows the salinity comparisons for all seven years.

## 7.0 WASP WATER QUALITY MODEL

The Water Quality Analysis Simulation Program Version 7.0 (WASP7) was used for the water quality model development described in this report. WASP7 was released by USEPA on April 27, 2005 on the Modeling Toolbox website (<http://www.epa.gov/athens/wqtsc/html/wasp.html>). This model calibration report contains a copy of the model so that reviewers can immediately assess this application for the Savannah River Estuary. WASP7 is the new version of WASP with many upgrades to the user's interface and the model's capabilities. The major upgrades to WASP have been the addition of multiple BOD components, addition of sediment diagenesis routines, and addition of periphyton routines. The TMDL model used WASP6 and the enhanced grid calibration was performed with WASP7, referred to from this point forward as just WASP. Figure 7-1 shows a diagram for the water quality model used in this application.

WASP is an enhanced Windows version of the USEPA Water Quality Analysis Simulation Program (WASP). The Windows version WASP has been developed to aid modelers in the implementation of WASP. With the new WASP, model execution can be performed up to ten times faster than the previous USEPA DOS version of WASP. Nonetheless, WASP uses the same algorithms to solve water quality problems as those used in the DOS version of WASP. WASP contains 1) a user-friendly Windows-based interface, 2) a pre-processor to assist modelers in the processing of data into a format that can be used in WASP, 3) high-speed WASP eutrophication and organic chemical model processors, and 4) a graphical postprocessor (MOVEM) for the viewing of WASP results and comparison to observed field data.

The new release of USEPA WASP was an enhancement of the original WASP (Di Toro et al., 1983; Connolly and Winfield, 1984; Ambrose, R.B. et al., 1988). WASP is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program. Water quality processes are represented in special kinetic subroutines that are either chosen from a library or written by the user. WASP is structured to permit easy substitution of kinetic subroutines into the overall package to form problem-specific models. WASP comes with two such models -- TOXI for toxicants and EUTRO for conventional water quality. Earlier versions of WASP have been used to examine eutrophication of Tampa Bay; phosphorus loading to Lake Okeechobee; eutrophication of the Neuse River and estuary; eutrophication and PCB pollution of the Great Lakes (Thomann, 1975; Thomann et al., 1976; Thomann et al., 1979; Di Toro and Connolly, 1980), eutrophication of the Potomac Estuary (Thomann and Fitzpatrick, 1982), kepone pollution of the James River Estuary (O'Connor et al., 1983), volatile organic pollution of the Delaware Estuary (Ambrose, 1987), and heavy metal pollution of the Deep River, North Carolina (JRB, 1984). In addition to these, numerous applications are listed in Di Toro et al., 1983.

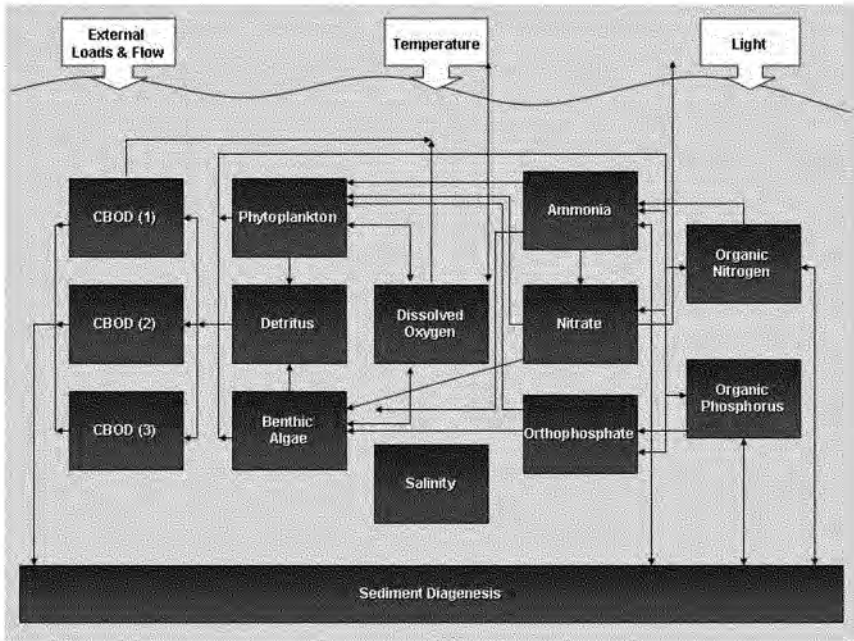


Figure 7-1 Water Quality Diagram for WASP

## 8.0 WASP APPLICATION TO THE SAVANNAH RIVER ESTUARY

Normal water quality modeling procedures were used to calibrate the Savannah Harbor model. Since there is limited algal activity or primary production in the harbor, nutrients were determined not to be a significant issue by EPA Region 4 and were not included in the water quality modeling scenarios. The water quality model incorporated normal oxygen dynamics, including reaeration, sediment oxygen demand (SOD), carbonaceous Biochemical Oxygen Demand (CBOD) and uptake, Nitrogenous Biochemical Oxygen Demand (NBOD) and uptake. The modeling approach was a five step process:

1. Incorporation of the hydrodynamic modeling results.
2. Determination of upstream and ocean boundary conditions.
3. Development of the point discharge loadings, marsh loadings and tributary loadings.
4. Determination of the instream modeling parameters and kinetic rates.
5. Calibration to measured water quality data.

### 8.1 Incorporation of the Hydrodynamic Modeling Results

The EFDC was used to perform the hydrodynamic simulations for the Savannah Harbor Estuary. The model and the application to Savannah Harbor is documented in the previous sections of this report. The model was run from 1997 through 2003.

Savannah Harbor EFDC hydrodynamic model provides to WASP:

- Ocean flow and tidal dynamics,
- Upstream flow,
- Three dimensional model cell structure and volumes,
- Cell volumes and transport,
- Salinity and Temperature

The hydrodynamic modeling information is incorporated into the WASP model through the hydrodynamic linkage file.

### 8.2 Determination of Upstream and Ocean Boundaries

#### 8.2.1 Headwater Boundary at USGS Clio Gage #02198500

The headwater or upstream boundary of the Savannah Harbor Model was at the USGS Clio Gage 02198500, 61 miles upstream from harbor mouth, the same as used in the EFDC Model. The headwater flows were based on USGS gaging record and incorporated through the EFDC model linkage. CBOD, NBOD and dissolved oxygen headwater boundary conditions were developed from field measurements and results of an upstream water quality model used by USEPA Region 4. USEPA adapted the EPD-RIVI hydrodynamic and water quality model to the Savannah River for 1997 through 2001. (USEPA, 2004) The original model was developed by GAEPD based on data collected by USEPA, Georgia and South Carolina during summers of 1990 and 1991. Updated point source discharges' CBOD, NBOD and dissolved oxygen loadings along with measured discharged flows were incorporated in the model. The Savannah River EPD-RIVI model was run under three scenarios:

- Background condition with no point source loadings.
- Existing conditions with DMR reported discharge flows and BOD5 and ammonia loads. F-ratios from 1990 and 1991 long-term data were used to develop the appropriate CBODu loadings. NBOD loads are equal to ammonia loads time a 4.57 conversion factor.
- Permit conditions using NPDES permitted flow and BOD5 and ammonia loads, along with the appropriate f-ratios

For the 1999 WASP model, the existing conditions run was used for CBODu, ammonia, nitrate-nitrite, and dissolved oxygen concentrations at Clio were used for the headwater boundary conditions. Figures 8-1, 8-2, and 8-3 illustrate the boundary concentrations calculated by the Savannah River EPD-RIV1 at Clio.

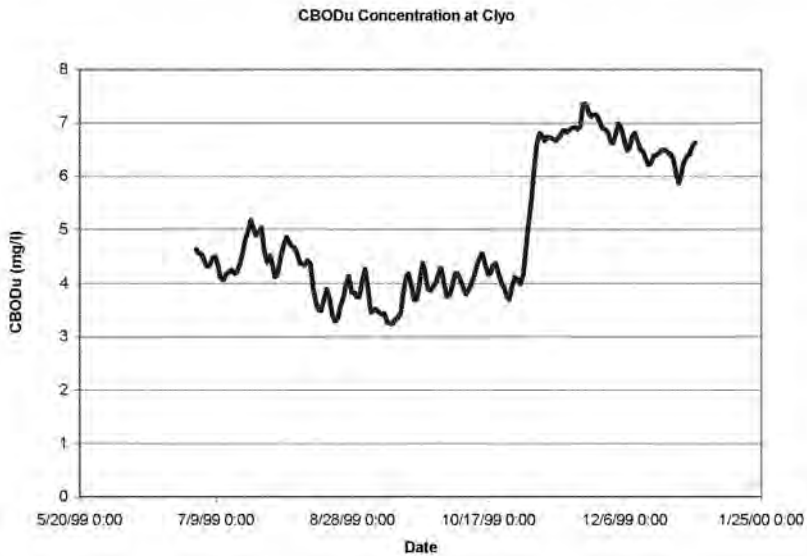


Figure 8-1 Headwater CBOD Concentrations at Clio

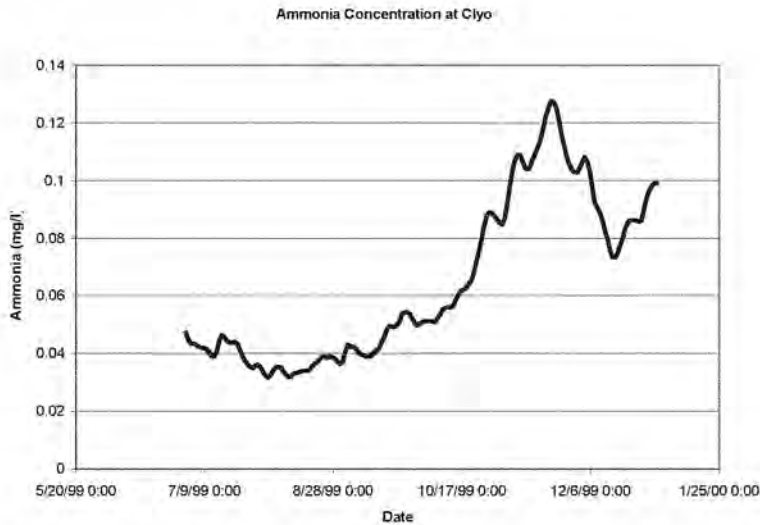


Figure 8-2 Headwater Ammonia Concentrations at Clio

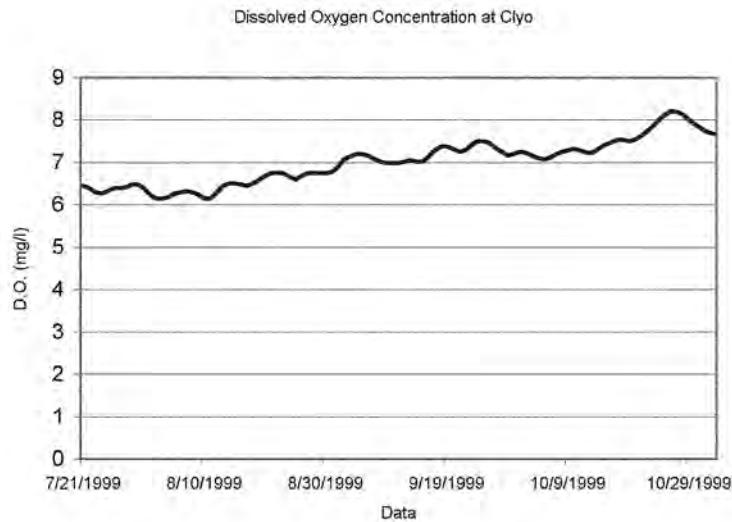


Figure 8-3 Headwater Dissolved Oxygen Concentrations at Clio

### 8.2.2 Ocean Boundary Conditions

Limited data were available to establish the ocean boundary DO, CBOD and ammonia concentrations. Ocean boundary dissolved oxygen levels (Figure 8-4) were set at 90% of dissolved oxygen saturation calculated from EFDC hydrodynamic model temperature and salinity results.

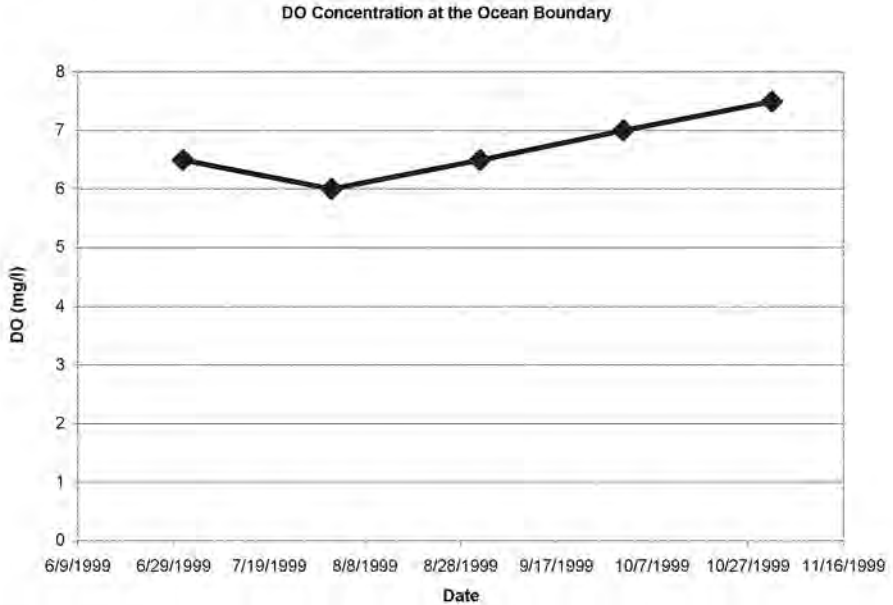


Figure 8-4 Dissolved Oxygen Concentration at the Ocean Boundary

CBOD<sub>u</sub> and ammonia values were determined from long-term BOD sampling conducted on September 2003. MACTEC (2004) reported the results of nine long-term ocean BOD samples collected by the Savannah Harbor Committee on September 24, 2003. These samples were collected during high wave conditions and may not be representative of long-term average BOD conditions. Table 8-1 shows the data collected by MACTEC at the ocean boundary. Based on the data in Table 8-1, the ocean boundary CBOD<sub>u</sub> was set at a constant 5 mg/L and ammonia set at 0.07 mg/L.

Table 8-1 Ocean Boundary Long-Term BOD

| Station                        | BOD <sub>u</sub><br>(mg/L) | CBOD <sub>u</sub><br>(mg/L) | K1<br>(1/day) | NBOD <sub>u</sub><br>(mg/L) | Kn<br>(1/day) |
|--------------------------------|----------------------------|-----------------------------|---------------|-----------------------------|---------------|
| SWS-01 South Ocean Boundary    | 5.67                       | 5.25                        | 0.03          | 0.42                        | 0.02          |
| SWS-02 Middle Ocean Boundary   | 4.07                       | 3.74                        | 0.04          | 0.34                        | 0.01          |
| SWS-03 Northern Ocean Boundary | 9.13                       | 8.82                        | 0.03          | 0.3                         | 0.01          |
| SWS-04 11.5 Miles Offshore     | 6.18                       | 5.67                        | 0.03          | 0.51                        | 0.01          |



Available USEPA data were used to establish 1997 Clio boundary conditions for dissolved oxygen and ammonia. Because of the lack of necessary dynamic data, the 1997 CBOD<sub>u</sub> boundary conditions for Clio and ocean boundary were set to 5.0 mg/L. The dynamic dissolved oxygen ocean boundary conditions have been set similar to 1999 scenario. All other state variables remained the same as the 1999 WASP model run.

### 8.3 Development of Point Source, Marsh, and Tributary Loadings

#### 8.3.1 Point Source Loads

Detailed point source CBOD and ammonia measurements were made during the 1999 Savannah Harbor Wastewater Characterization Study (Law Engineering, 1999). For the remaining time periods, the facility's Discharge Monitoring Reports (DMR) data were used to develop the appropriate loads.

A summary of the summer 1999 loads are included in Table 8-2. Detailed time series loads were incorporated into the model when daily values were available (index TS in Table 8-2), otherwise an average loads were used. So tabulated in cells with (TS) numbers display only estimated average values but are not used in the model set-up. The following calculations and nomenclature were used:

- CBOD<sub>u</sub> (Ultimate CBOD) = BOD5 times f-ratio,
- NBOD<sub>u</sub> (Ultimate NBOD) = Ammonia times 4.57, and
- TBOD<sub>u</sub> (Ultimate Total BOD) = CBOD<sub>u</sub> plus NBOD<sub>u</sub>.

Table 8-2 Point Source Loads for Summer 1999

| Facility name       | NPDES     | Flow (mgd) | CBOD <sub>u</sub> (kg/day) | NH3 (kg/day) |
|---------------------|-----------|------------|----------------------------|--------------|
| Hardeeville         | SC0034584 | 0.5 (TS)   | 11 (TS)                    | 0.2          |
| Fort James          | GA0046973 | 19.3 (TS)  | 1830 (TS)                  | 22           |
| Smurfit Stone       | GA0002798 | 2.6        | 280                        | 1.1          |
| Garden City         | GA0031038 | 1.1        | 64 (TS)                    | 0.4          |
| Whilshire           | GA0020443 | 3.1        | 292 (TS)                   | 117 (TS)     |
| Travis Field        | GA0020447 | 0.8        | 56 (TS)                    | 0.3 (TS)     |
| President Street    | GA0025348 | 19.0 (TS)  | 2,129 (TS)                 | 93 (TS)      |
| International Paper | GA0001998 | 30.0 (TS)  | 25,010 (TS)                | 125          |
| Englehard           | GA0048330 | 1.0        | 14                         | 66           |
| Kerr McGee*         | GA0003646 | 13.0       | 299                        | NA           |

\*NOTES: Kerr McGee has an immediate oxygen demand load of 11,519 lbs/day (5,225 kg/day)

Table 8-3 Point Source Loads for Summer 1997

| Facility name       | NPDES     | Flow (mgd) | CBODu (kg/day) | NH3 (kg/day) |
|---------------------|-----------|------------|----------------|--------------|
| Hardeeville         | SC0034584 | 0.5 (TS)   | 11.0           | 0            |
| Fort James          | GA0046973 | 19.3 (TS)  | 1,410 (TS)     | 10           |
| Smurfit Stone       | GA0002798 | 2.6        | 2,573 (TS)     | 1.1          |
| Garden City         | GA0031038 | 1.1        | 32 (TS)        | 0.1          |
| Whilshire           | GA0020443 | 3.1        | 165 (TS)       | 53.2 (TS)    |
| Travis Field        | GA0020447 | 0.8        | 55 (TS)        | 0.2 (TS)     |
| President Street    | GA0025348 | 18.8       | 2,138 (TS)     | 30 (TS)      |
| International Paper | GA0001998 | 30 (TS)    | 34,645 (TS)    | 56.8         |
| Englehard           | GA0048330 | 1          | NA             | 30           |
| Kerr McGee*         | GA0003646 | 13         | NA             | NA           |

\*NOTES: Kerr McGee has an immediate oxygen demand load of 11,519 lbs/day

Table 8-4 NPDES Discharge Concentrations for Summers 1997 and 1999

| Facility name                      | NPDES     | Flow (mgd) | DO (mg/L) | NH3 (mg/L) | NO3-NO2 (mg/L) | CBODu (mg/L) |
|------------------------------------|-----------|------------|-----------|------------|----------------|--------------|
| Hardeeville                        | SC0034584 | 0.5        | 6         | NA         | 0.3            | NA           |
| Fort James                         | GA0046973 | 19.3       | 6         | NA         | 0.3            | NA           |
| Smurfit Stone                      | GA0002798 | 2.6        | 6         | NA         | 0.3            | NA           |
| Garden City                        | GA0031038 | 1.1        | 6         | NA         | 0.3            | NA           |
| Wilshire                           | GA0020443 | 3.1        | 6         | NA         | 0.3            | NA           |
| Travis Field                       | GA0020447 | 0.8        | 6         | NA         | 0.3            | NA           |
| President Street                   | GA0025348 | 18.8       | 6         | NA         | 0.3            | NA           |
| International Paper                | GA0001998 | 30         | 6         | NA         | 0.3            | NA           |
| Englehard                          | GA0048330 | 1          | 6         | NA         | 0.3            | NA           |
| Kerr McGee                         | GA0003646 | 13         | 6         | NA         | 0.3            | NA           |
| Savannah Electric Plant Macintosh* |           | 130        | 6         | See note   | See note       | See note     |
| Savannah Electric Port Wentworth*  |           | 258        | 6         | See note   | See note       | See note     |
| Riverside Power Plant*             |           | 49         | 6         | See note   | See note       | See note     |

\*NOTE: For the Savannah Electric Plant Macintosh, Savannah Electric Port Wentworth, and the Riverside Power Plant, the return flows have consistent concentrations as the intake concentrations. For the heat loads of the power plants, see Table 4-6 in Section 4.4.5.

Figures 8-5 through 8-11 illustrate the variability of the various major harbor discharges.

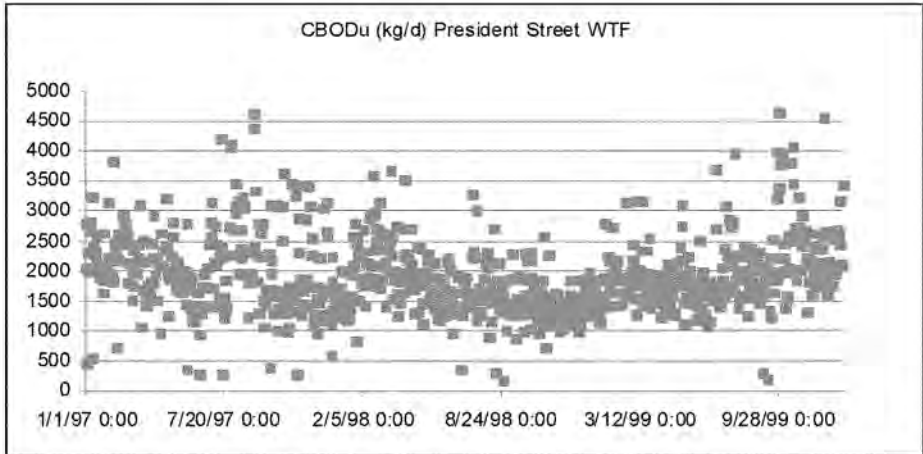


Figure 8-5 President Street CBODu Load

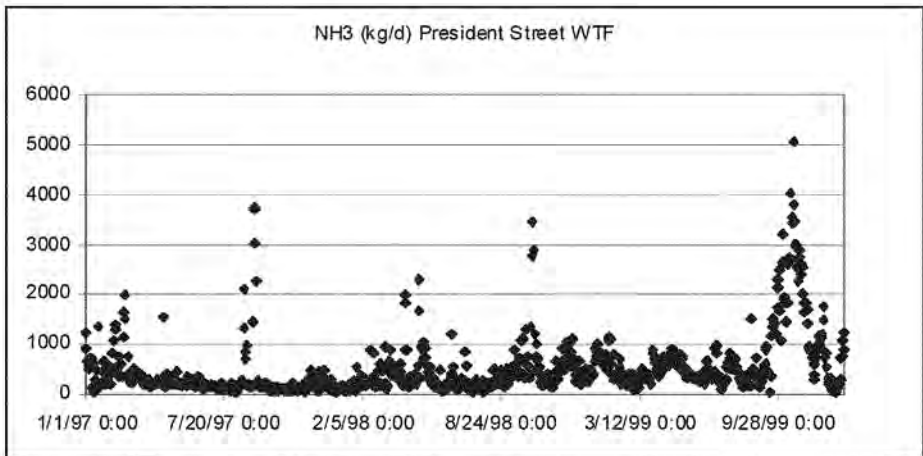


Figure 8-6 President Street Ammonia Load

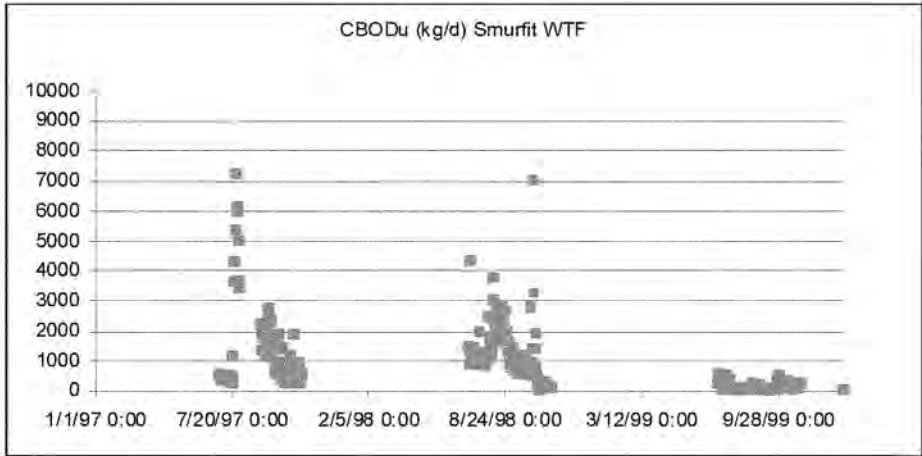


Figure 8-7 Smurfit Stone CBODu Load

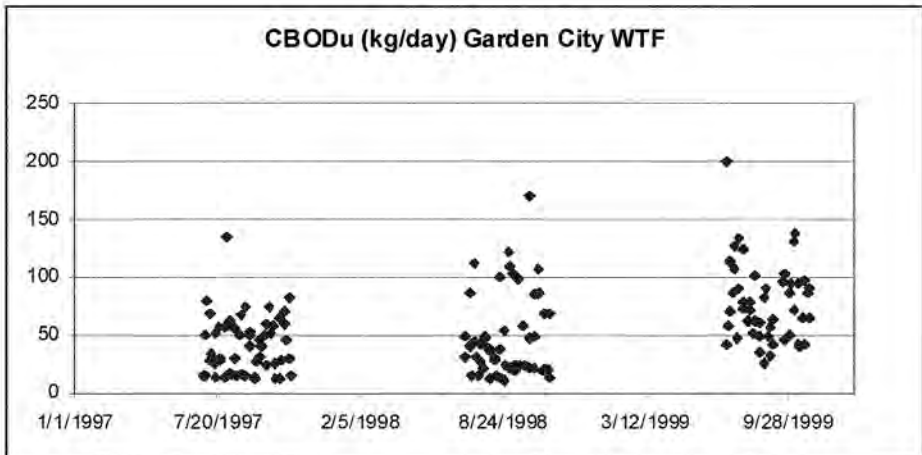


Figure 8-8 Garden City CBODu Load

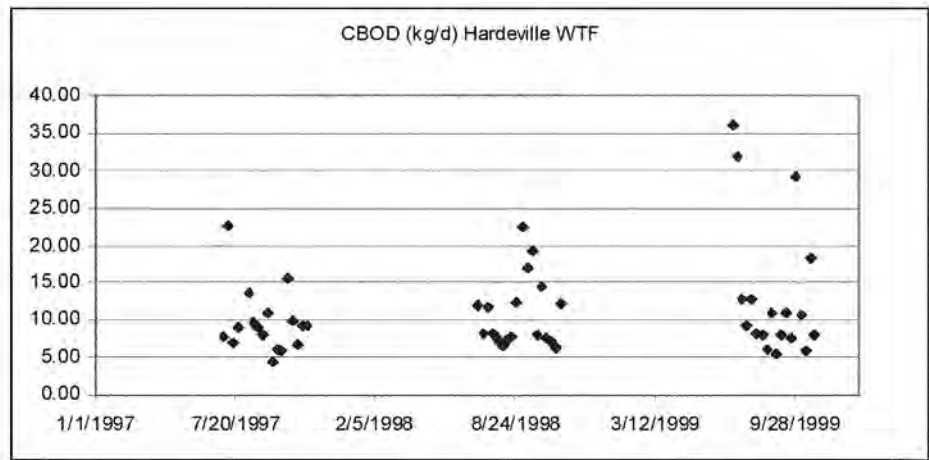


Figure 8-9 Hardeville CBODu Load

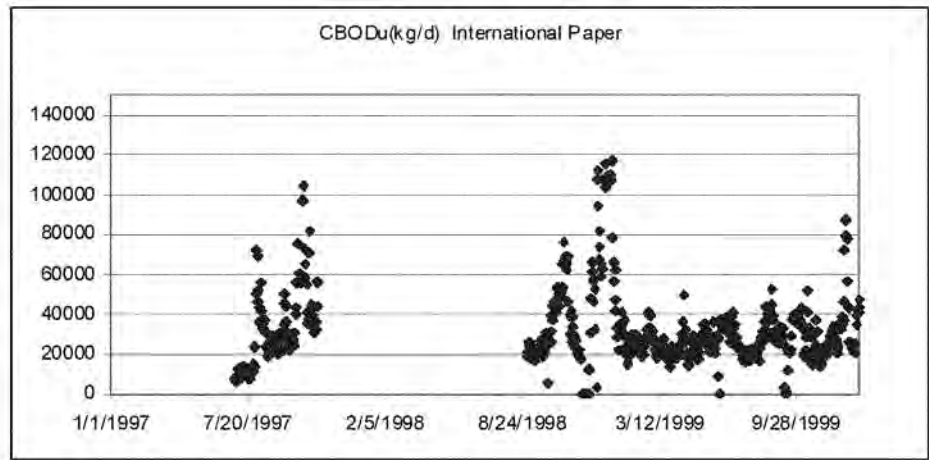


Figure 8-10 International Paper CBODu Load

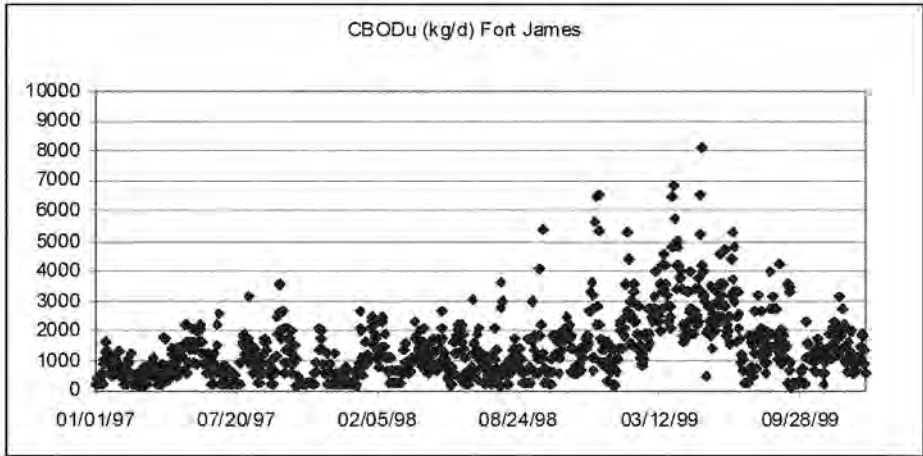


Figure 8-11 Fort James Paper CBODu Load

### 8.3.2 Marsh Loadings

The adjacent marsh areas in the Lower Savannah River and Estuary (Harbor) effect significantly the dissolved oxygen concentrations in the Front River. The marsh areas are important for the hydrodynamics in the way they affect the salinity transport on the Middle and Little Back Rivers. Therefore, it was determined that the inclusion of the marsh areas into the model was necessary for capturing the salinity trends in the upper part of the estuary. The modeled marsh areas would also provide a mechanism to simulate CBODu loadings from the marsh areas into Savannah Harbor. As described in detail in Section 4.4.3, a simple, but comprehensive solution was developed to handle the marsh areas in the EFDC hydrodynamic and WASP water quality models. The enhanced EFDC model includes 17 separate marsh areas to represent the 10 Q zones of the estuarine marshes from the Tidegate to I-95. Only 15 of the marshes were used as water quality loads. The Union Creek and Augustine Creek sites were used as storage only.

To quantify the exchange of organic material between marshes and the open water of the Savannah Harbor, previous studies were reviewed to develop appropriate loading rates. The following studies were reviewed and used to quantify the marsh loadings.

- GPA field data during Summer of 1999 – marsh data (ATM, 2000).
- Maybank Project: A Study of the Intertidal Marshes and Streams. USEPA Environmental Services Division, Athens, Georgia, May 1984 (USEPA, 1984).
- Burke III, Roy 1984. Proposed Protocol for: Incorporating the Effects of a Spartine Salt Marsh into a Simplified Water Quality Model of Adjacent Tidal Waters in Georgia. US USEPA, Region 4 (Burke, 1984).
- Nutrient Dynamics and Water Quality Interactions in the Goose Creek Sub-Basin of the Charleston Harbor Estuary. Department of Environmental Health Science University of South Carolina, Columbia, SC, October 1996 (McKellar, 1996).

- Nixon, Scott W. and Virginia Lee. Wetlands and Water Quality. Technical Report Y-86-2, October 1986 (Nixon, 1986).

Results of all long-term BOD (LTBOD) sampling at Marsh Exchange Transect sites in the lower Savannah River (ATM, 2000) demonstrate that all BOD samples collected during mid-ebbing tides exceed the values of BOD collected during corresponding mid-flooding tides. This indicates that marshes in Savannah Harbor export organic matter to open waters of the harbor.

The initial CBOD<sub>u</sub> loading from the marsh were based on maximum literature export coefficient, the long-term data collect by ATM in 1999 (ATM, 2000), and data analyses completed by MACTEC. The marsh CBOD<sub>u</sub> loadings were calculated based on the long-term BOD data as a maximum loading value. The 50% reduction of the calculated maximum loads is a reasonable assumptions considering the complete marsh area is not flooded over every tidal cycle, thus not all of the marsh area will export a CBOD load. The results are shown in Tables 8-5 and 8-6. The marsh loads were distributed in the top three layers of the model in WASP.

Table 8-5 Marsh CBOD Loading Calculations

| Channel CBOD Model Predicted (mg/L) based on Maximum Loads | Measured CBOD (mg/L) | Calculated Ratio of Model output to measured CBOD <sub>u</sub> | Measured Ammonia (mg/L) | Marsh Data Collection Station |
|------------------------------------------------------------|----------------------|----------------------------------------------------------------|-------------------------|-------------------------------|
| 8                                                          | 3.5                  | 0.44                                                           | 0.3                     | 4                             |
| 25                                                         | 10                   | 0.40                                                           | 0.3                     |                               |
| 20                                                         | 10                   | 0.50                                                           | 0.3                     | 5                             |
| 9                                                          | 4.5                  | 0.50                                                           | 0.3                     |                               |
| 12                                                         | 4.5                  | 0.38                                                           | 0.3                     | 4                             |
| 7                                                          | 3.5                  | 0.50                                                           | 0.3                     | 1 & 3                         |
| 7                                                          | 4.5                  | 0.64                                                           | 0.3                     |                               |
| 9                                                          | 3.5                  | 0.39                                                           | 0.3                     | 2                             |
| 16                                                         | 10                   | 0.63                                                           | 0.3                     |                               |
|                                                            |                      | Average = 0.49                                                 |                         |                               |

Table 8-6 Marsh CBOD<sub>u</sub> Loads by Q-Zone

| QZONE | Marsh Type | CBOD Load (kg/d) |
|-------|------------|------------------|
| 1     | Fresh      | 900              |
| 2     | Salt       | 38,100           |
| 3     | Salt       | 18,000           |
| 4     | Mixed      | 11,110           |
| 5     | Fresh      | 1,848            |
| 6     | Fresh      | 2,550            |
| 7     | Mixed      | 750              |
| 8     | Fresh      | 1,518            |
| 9     | Fresh      | 2,550            |
| 10    | Mixed      | 630              |

## 8.4 Model Kinetics

Model kinetics and parameters determine the decay of the pollutants and the oxygen uptake amount in the system. These kinetic rates and parameters are determined based on the measured data and standard water quality modeling assumptions. The parameters are shown in Table 8-7.

The main rates and parameters are:

- Decay rate  $K_1$  (1/day) for Carbonaceous BOD,
- Decay rate  $K_1$  (1/day) for Ammonia and Rest of Nitrogen Series,
- Sediment Oxygen Demand (gram/meter<sup>2</sup>/day), and
- Reaeration (1/day).

Table 8-7 Rates and Constants in WASP Model

| Rate                                               | Value                          |
|----------------------------------------------------|--------------------------------|
| Nitrification rate at 20 °C                        | 0.035                          |
| Nitrification Temperature Coefficient              | 1.08                           |
| Half Saturation: Nitrification Oxygen Limitation   | 1                              |
| Denitrification rate at 20 °C                      | 0.1                            |
| Denitrification Temperature Coefficient            | 1.08                           |
| Half Saturation: Denitrification Oxygen Limitation | 0                              |
| Reaeration Option                                  | O'Connor<br>(Wind + Hydraulic) |
| Reaeration Temperature Correction                  | 1.024                          |
| Oxygen:Carbon Stoichiometric Ratio                 | 2.66                           |
| Offshore Correction Factor for BOD Decay Rate      | 0.5                            |
| BOD Decay Rate Temperature Correction              | 1.047                          |
| BOD Half Saturation Oxygen Limit                   | 0.5                            |
| Fraction of BOD Carbon Source for Denitrification  | 2.66                           |
| Sediment Oxygen Demand                             | 0.5 to 1.2                     |
| Sediment Oxygen Demand Temperature Correction      | 1.065                          |
| Offshore Wind Correction Factor                    | 6                              |

### 8.4.1 Decay Rate $K_1$ (1/day) for Carbonaceous BOD

The CBOD represents the oxygen demanding equivalent of the complex organic carbonaceous material in water. The ultimate CBOD (CBOD<sub>u</sub>) and the initial CBOD decay rates were determined from the long-term BOD results summarized in the Savannah Harbor Expansion Project TMDL 1999 River and Marsh Long-term Biochemical Oxygen Demand Results (Federal Agencies, 2004). This report, lead by Dr. Roy Burke at GAEPD, provided backup documentation for the 39 long-term BOD samples collected during the 1999 intensive summer survey.

The distinction between "bottle" BOD rates and the loss rate (or decay rate) of BOD in surface water depends on the type and size of the receiving water body. For shallow streams, one would expect the in-stream decay rate to be higher than the bottle rate due to the influence of the benthic community located on the sides and bottom of the stream bed. For larger streams and estuaries, where the volume of water is large compared to the area of the sides and bottom, the river or estuary decay rate will be equivalent to the measured bottle rate and the measured bottle rates are good indicators of the actual stream CBOD decay



rates. A temperature correction factor 1.047 was used to adjust the CBOD decay rate for the changes in temperature. The measurements from 1999 are shown in Table 8-8.

Table 8-8 Measured Long-term BOD rates and F-ratios

| Survey No.                              | Slack Tide | Ultimate Carbonaceous BOD |                 |         | Ultimate Nitrogenous BOD |                 |
|-----------------------------------------|------------|---------------------------|-----------------|---------|--------------------------|-----------------|
|                                         |            | mg/L                      | K1 Rate per day | f-ratio | mg/L                     | Kn Rate per day |
| Station 1. Ft. Pulaski. River Mile 0.8  |            |                           |                 |         |                          |                 |
| 1                                       | High       | 2.99                      | 0.062           | 3.75    | 1.77                     | 0.029           |
| 2                                       | High       | 4.25                      | 0.105           | 2.45    | 1.88                     | 0.027           |
| 3                                       | High       | 2.62                      | 0.081           | 3.02    | 2.26                     | 0.018           |
| 1                                       | Low        | 2.81                      | 0.076           | 3.17    | 1.60                     | 0.032           |
| 2                                       | Low        | 3.09                      | 0.047           | 4.75    | 1.27                     | 0.051           |
| 3                                       | Low        | 3.52                      | 0.084           | 2.90    | 1.68                     | 0.034           |
| Average =                               |            | 3.21                      | 0.076           | 3.34    | 1.74                     | 0.032           |
| Station 2. Ft. Jackson. River Mile 10.6 |            |                           |                 |         |                          |                 |
| 1                                       | High       | 3.03                      | 0.055           | 4.15    | 2.08                     | 0.030           |
| 2                                       | High       | 3.24                      | 0.062           | 3.77    | 1.49                     | 0.062           |
| 3                                       | High       | 2.46                      | 0.082           | 3.00    | 1.77                     | 0.040           |
| 1                                       | Low        | 2.88                      | 0.057           | 4.02    | 1.73                     | 0.032           |
| 2                                       | Low        | 2.96                      | 0.081           | 3.83    | 1.54                     | 0.059           |
| 3                                       | Low        | 2.54                      | 0.072           | 3.30    | 1.72                     | 0.027           |
| Average =                               |            | 2.85                      | 0.065           | 3.68    | 1.72                     | 0.042           |
| Station 3. Corps Dock. River Mile 16.6  |            |                           |                 |         |                          |                 |
| 2                                       | High       | 2.38                      | 0.034           | 6.48    | 0.80                     | 0.055           |
| 3                                       | High       | 2.58                      | 0.070           | 3.37    | 1.62                     | 0.032           |
| 1                                       | Low        | 2.64                      | 0.054           | 4.20    | 1.31                     | 0.018           |
| 2                                       | Low        | 2.38                      | 0.034           | 6.48    | 0.80                     | 0.055           |
| 3                                       | Low        | 2.33                      | 0.064           | 3.67    | 1.59                     | 0.023           |
| Average =                               |            | 2.46                      | 0.051           | 4.84    | 1.22                     | 0.037           |
| Station 4. I-95 Bridge. River Mile 27.7 |            |                           |                 |         |                          |                 |
| 3                                       | High       | 1.69                      | 0.065           | 3.59    | 0.91                     | 0.018           |
| 1                                       | Low        | 2.29                      | 0.066           | 3.68    | 0.79                     | 0.018           |
| 2                                       | Low        | 2.19                      | 0.028           | 7.78    | 0.64                     | 0.037           |
| 3                                       | Low        | 1.87                      | 0.067           | 3.49    | 1.24                     | 0.018           |
| Average =                               |            | 2.01                      | 0.057           | 4.64    | 0.90                     | 0.023           |
| Clyo, Georgia. River Mile 61.0          |            |                           |                 |         |                          |                 |
| 1                                       | ---        | 3.10                      | 0.078           | 3.09    | 0.92                     | 0.027           |
| 2                                       | ---        | 3.65                      | 0.071           | 3.34    | 2.04                     | 0.038           |
| 3                                       | ---        | 1.68                      | 0.068           | 3.49    | 0.38                     | L               |
| Average =                               |            | 2.81                      | 0.072           | 3.31    | 1.11                     | 0.033           |

The Savannah Harbor is a complex system which receives wastewater with various types of long-term BOD characteristics. For example, pulp mill wastewater that has a low bottle decay rate, CBOD<sub>u</sub> concentration and high f-ratio. There have been multiple discussions on how to assign an appropriate decay rate that accurately accounts for the impact of these low BOD decay rate wastewaters. One method would be to assume each wastewater discharge acts independently in the receiving water and assign a unique CBOD decay rate to each wastewater discharge that is equivalent to their respective bottle rate. The other method is to assume the wastewater and receiving waters' concentration of organic material combine and the oxidation of the organic carbon in a body of water is a single rate that decays the combine CBOD<sub>u</sub>. The second approach was most supported by USEPA and GAEPD, so it is the method used in the Savannah Harbor modeling described herein.

Based on the long-term BOD data and analyses, spatial varying K1 rates, as reported in Table 8-9, were assigned to the various portions of the harbor model.

Table 8-9 Spatial Distribution of CBODu Decay Rates (1/day)

| Harbor Segment                                   | K1 Scale Factor |
|--------------------------------------------------|-----------------|
| Savannah River (from Clio to K.I. Turning Basin) | 0.92-1.08       |
| Front River                                      | 0.83-1.08       |
| Middle River                                     | 0.83-0.92       |
| Back and Little Back Rivers                      | 0.5             |
| Offshore                                         | 0.5-0.67        |
| F.R. Sediment Basin                              | 0.5-0.67        |
| Sediment Basin                                   | 0.92-1.08       |
| Turning Basin                                    | 0.92-1.08       |
| South Channel                                    | 0.92-1.08       |
| Union Creek                                      | 1.08            |
| Marshes                                          | 0.83-0.92       |

For the point source dischargers, the LTBD demonstrated various types of long-term BOD characteristics. For example, pulp mill wastewater that has a low bottle decay rate, CBODu concentration and high f-ratio. There have been multiple discussions on how to assign an appropriate decay rate that accurately accounts for the impact of these different BOD decay rate wastewaters. Dr. Roy Burke III of Georgia EPD has re-evaluated the Savannah Harbor long-term data using the updated GAEPD LTBD program. These results are located in Table 8-10 and described below. Based on extensive data analyses and taking into account existing limitations of the WASP code the following LTBD approach is proposed.

The Enhanced Savannah Harbor water quality model will use three carbonaceous decay rates. These three rates are selected based on Dr. Burke's initial LTBD analyses. Using these three rates, each discharge and boundaries conditions' ultimate CBOD and resultant f-ratio, were determined using a one or two component CBOD LTBD analysis.

- Fast acting K1 rate of 0.12/day with an f-ratio of 2.3
- Middle K1 rate of 0.06/day with an f-ratio of 5
- Slow acting K1 rate of 0.02/day with an f-ratio of 10.5

The long-term BOD analysis (LTBD program) was conducted using the following steps:

- NBOD curve determined using a lag first order curve fit:
  - The curve subtracted from long-term time series to yield CBOD time series.
  - NBODult determined.
- Fast or initial acting CBOD component using first order curve fit:
  - This resultant curve was also subtracted to yield the residue CBOD.
  - CBODult1 and f-ratio determined.
- Slow acting CBOD component using a lagged first order curve fit with 0.02/day rate:

- The normal in bottle lag time was 20 to 40 days.
- CBOD<sub>ult</sub>2 and f-ratio determined.
- For the dual rate component WTF discharges:
  - Total CBOD<sub>ult</sub> and the percentage of fast acting and slow acting CBOD<sub>ult</sub> were determined.
  - CBOD<sub>5</sub> was determined from the initial CBOD curve fit.
  - This total CBOD<sub>ult</sub> (CBOD<sub>1</sub> plus CBOD<sub>2</sub>) was divided by this CBOD<sub>5</sub> to determine the combined f-ratio.
  - Using the combined f-ratio the total CBOD<sub>ult</sub> can be determined from the WTF's CBOD<sub>5</sub> time series and then divided in to the appropriate loading category.

Based on the described analyses, the following CBOD decay rates in Table 8-10 were assigned.

Table 8-10    CBOD<sub>u</sub> Decay Rates (1/day)

| Source/Water          | % of total discharge | K1 (1/day) | F-ratio |
|-----------------------|----------------------|------------|---------|
| Hardeeville (fast)    | 50                   | 0.12       | 2.3     |
| Hardeeville (slow)    | 50                   | 0.02       | 10.5    |
| Fort James (fast)     | 50                   | 0.12       | 2.3     |
| Fort James (slow)     | 50                   | 0.02       | 10.5    |
| Smurfit Stone (fast)  | 65                   | 0.12       | 2.3     |
| Smurfit Stone (slow)  | 35                   | 0.02       | 10.5    |
| Garden City           | 100                  | 0.02       | 10.5    |
| Wilshire              | 100                  | 0.02       | 10.5    |
| Travis Field          | 100                  | 0.02       | 10.5    |
| President Street      | 100                  | 0.02       | 10.5    |
| International Paper   | 100                  | 0.02       | 10.5    |
| Englehard             | 100                  | 0.06       | 5.0     |
| Marshes               | 100                  | 0.06       | 5.0     |
| Clyo boundary (fast)  | 70                   | 0.12       | 2.3     |
| Clyo boundary (slow)  | 30                   | 0.02       | 10.5    |
| Ocean Boundary (fast) | 50                   | 0.12       | 2.3     |
| Ocean Boundary (slow) | 50                   | 0.02       | 10.5    |

#### 8.4.2 Ammonia Reaction Rates

A uniform ammonia  $K_n$  rate of 0.035/day was based on measured rates from long-term BOD analyses. See CBOD<sub>u</sub> rates discussion. A temperature correction factor 1.08 was used to adjust the  $K_n$  rate for the changes in temperature.

#### 8.4.3 Sediment Oxygen Demand

The sediment oxygen demand (SOD) in rivers and estuaries may result from the discharge of settleable organic solids, urban runoff and upstream nonpoint sources of organic materials. The SOD in the Savannah Harbor system were last measured in 1999 and are reported in the 1999 USEPA Region 4 study "Dissolved Oxygen Diffusion Study and Sediment Oxygen Demand Study, Savannah River, Savannah, Georgia, August 2 – 14, 1999". The average SOD measurements in the main portion of the Front River were 1.1 grams/meter<sup>2</sup>/day at 30 degrees Celsius with a SOD range of 0.86 to 1.3. This value was used as a starting SOD value for the model. Higher SOD rates of 2.58 grams/ meter<sup>2</sup>/day at 30 degrees Celsius were measured in the Kings Island Turning Basin. The 1.2 grams/ meter<sup>2</sup>/day SOD at 20 degrees Celsius was used as a starting value for the Turning Basin and the downstream Sediment Basin and 0.7 to 0.9 for the Front and Savannah Rivers and 0.65 for rest of system. A temperature correction factor 1.065 was used to adjust the SOD rate for the changes in temperature. Figure 8-12 is output from the WASP model and shows how SOD varies over time in the sediment and turning basins in comparison to the rest of the harbor.

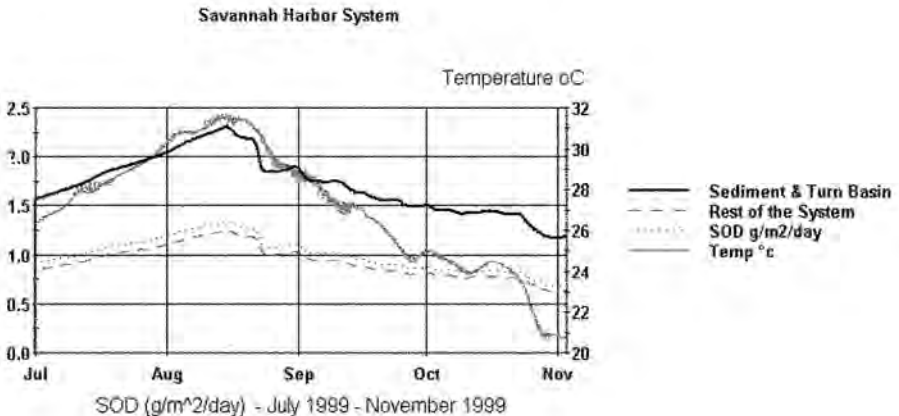


Figure 8-12 SOD (g/m<sup>2</sup>/day) for Savannah Harbor System

#### 8.4.4 Reaeration

Oxygen transfer in natural waterbodies depends on internal mixing and turbulence due to velocity gradients and fluctuations, temperature, wind mixing, waterfalls, dams and rapids and surface films. (Thomann and Mueller, 1987) For the Savannah Harbor system, a time varying tidal reaeration using the O'Connor Dobbins formulation, incorporating the model's surface layer predicted depths and velocities,

was used to calculate this oxygen transfer. For the open ocean portion of the model and the harbor mouth area, the wind-induced reaeration option was used to calculate the oxygen transfer. O'Connor-Dobbins reaeration formulation was developed to be applied to estuaries using average tidal velocity and depth. To adjust the WASP-calculated reaeration value, a factor of 0.2 was applied. This factor was determined through the dissolved oxygen calibration process. A temperature correction factor of 1.024 was used to adjust the reaeration rate for the changes in temperature.

Diffusion in the Savannah Harbor system was measured in 1999 and are reported in the 1999 USEPA Region 4 study as reported in "Dissolved Oxygen Diffusion Study and Sediment Oxygen Demand Study, Savannah River, Savannah, Georgia, August 2 – 14, 1999". The diffusion measurements were compared to the model predicted reaeration results and it indicated that the calculated reaeration values are in line with the measured reaeration values using the diffusion dome method. Figure 8-13 is output from the WASP model and shows how reaeration varies over time in the Front River, Savannah River, and open ocean.

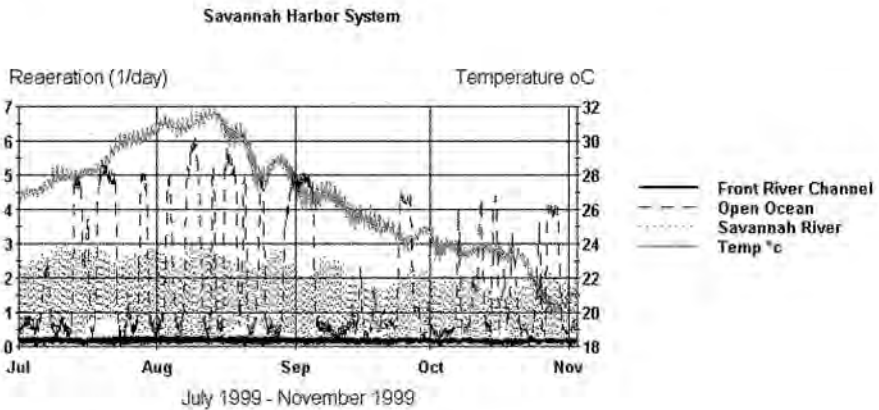


Figure 8-13 Reaeration (1/day) for Savannah Harbor System

Table E-1 1997 Currents (m/s) Statistical Comparisons for July 9, 1997 through October 6, 1997

| July 9 - October 5, 1997<br>[Julian Days 191 - 279] |       |          |       |      |           |       |      |             |      |
|-----------------------------------------------------|-------|----------|-------|------|-----------|-------|------|-------------|------|
| Stations                                            | Depth | Measured |       |      | Simulated |       |      | Differences |      |
|                                                     |       | 5%       | 50%   | 95%  | 5%        | 50%   | 95%  | 5%          | 95%  |
| FR-04                                               | S     | -0.88    | 0.09  | 0.82 | -1.10     | -0.49 | 0.76 | -24%        | 7%   |
| FR-04                                               | B     | -0.66    | 0.18  | 0.77 | -0.34     | 0.13  | 0.67 | 48%         | 13%  |
| FR-08                                               | S     | -0.87    | -0.16 | 0.78 | -1.05     | -0.41 | 0.86 | -20%        | -10% |
| FR-08                                               | B     | -0.76    | -0.10 | 0.58 | -0.73     | -0.25 | 0.63 | 4%          | -9%  |

S = Surface

B = Bottom

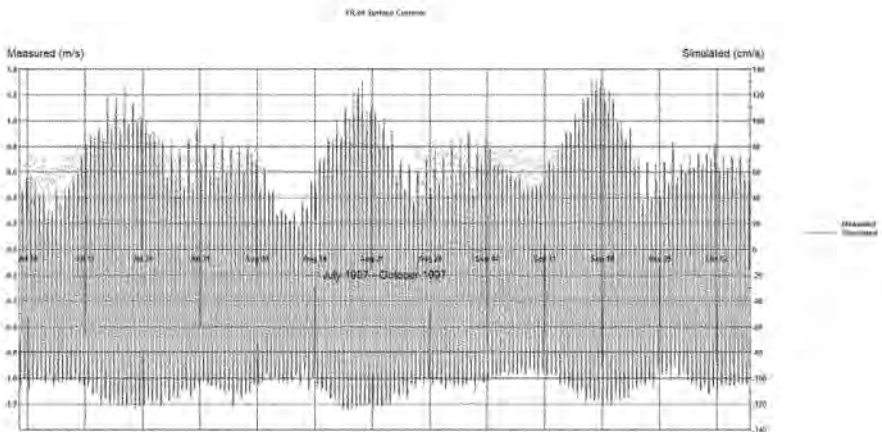


Figure E-1 Currents Comparison at FR-04 Surface for July 9, 1997 through October 6, 1997

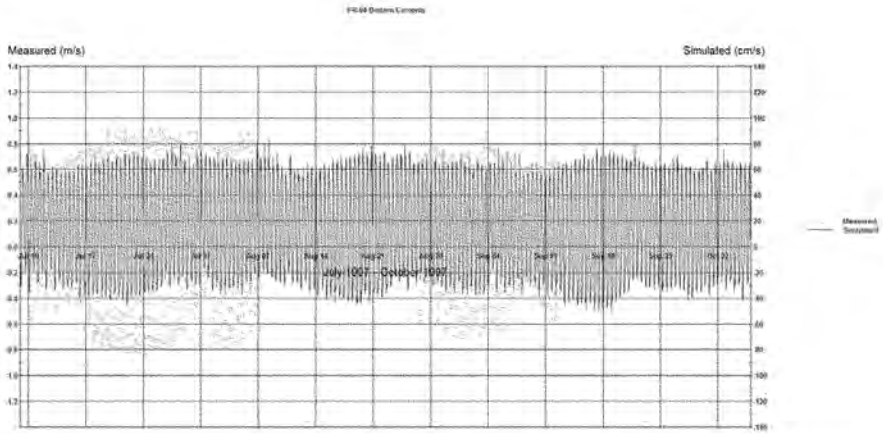


Figure E-2 Currents Comparison at FR-04 Bottom for July 9, 1997 through October 6, 1997

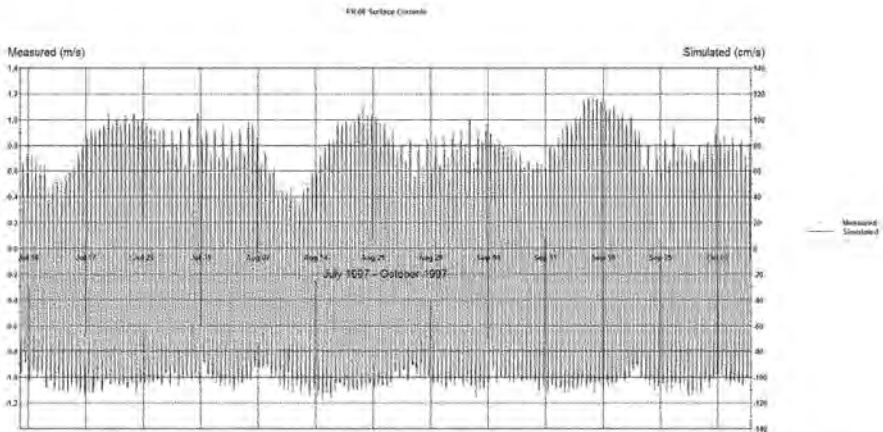


Figure E-3 Currents Comparison at FR-08 Surface for July 9, 1997 through October 6, 1997

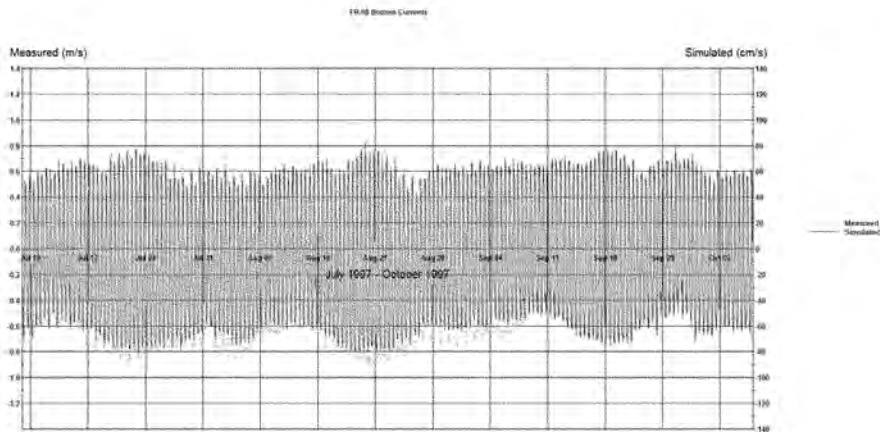


Figure E-4 Currents Comparison at FR-08 Bottom for July 9, 1997 through October 6, 1997



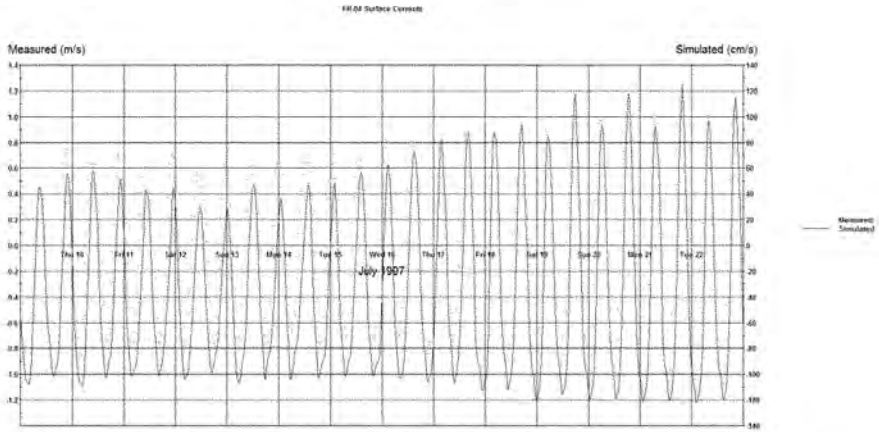
**2-Week Currents Plots**

Figure E-5 Currents Comparison at FR-04 Surface for July 9, 1997 through July 23, 1997

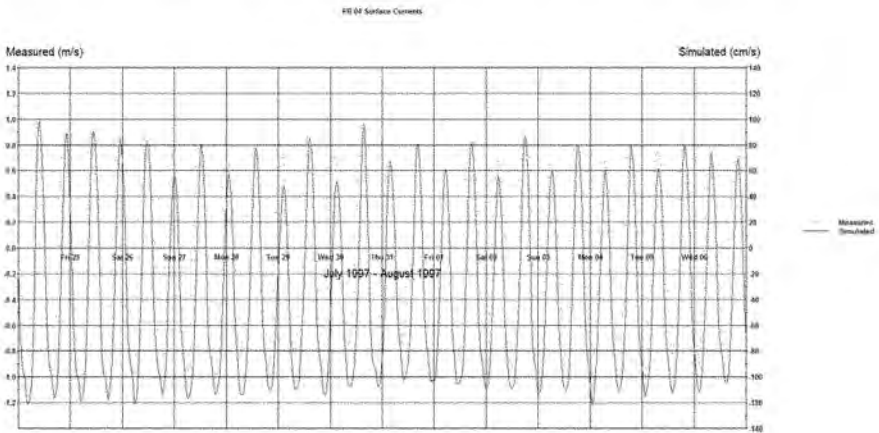


Figure E-6 Currents Comparison at FR-04 Surface for July 24, 1997 through August 7, 1997

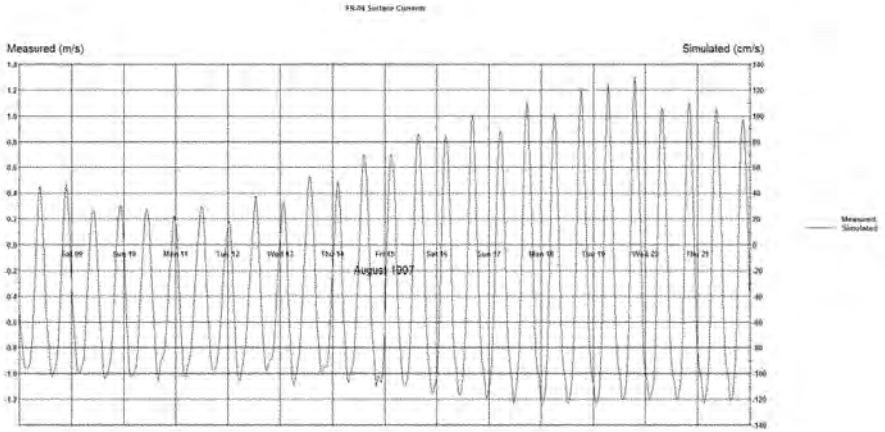


Figure E-7 Currents Comparison at FR-04 Surface for August 8, 1997 through August 22, 1997

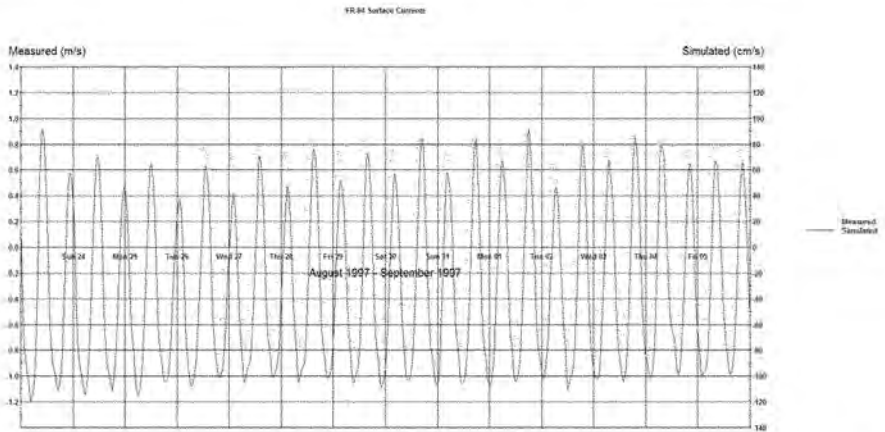


Figure E-8 Currents Comparison at FR-04 Surface for August 23, 1997 through September 6, 1997

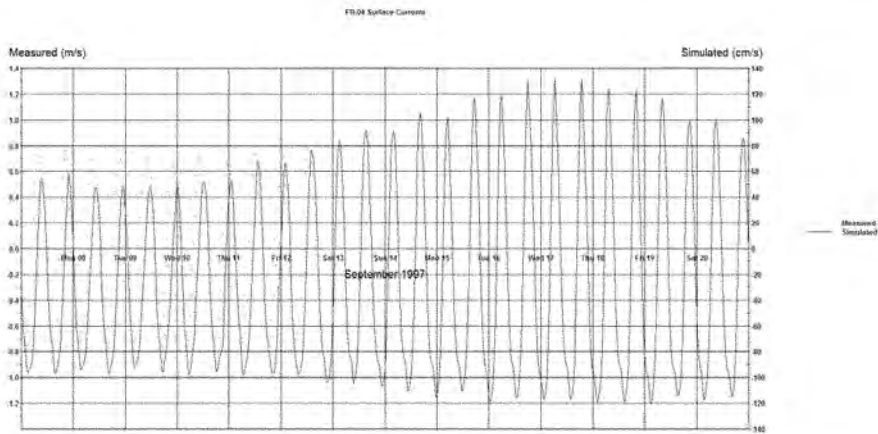


Figure E-9 Currents Comparison at FR-04 Surface for September 7, 1997 through September 21, 1997

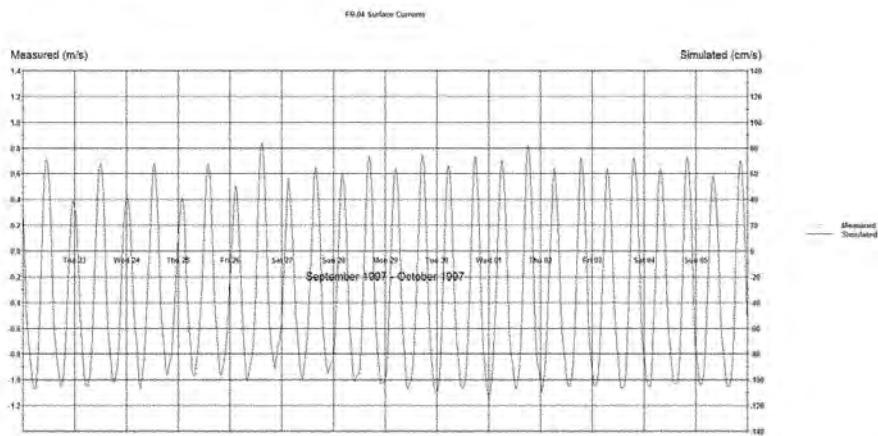


Figure E-10 Currents Comparison at FR-04 Surface for September 22, 1997 through October 6, 1997

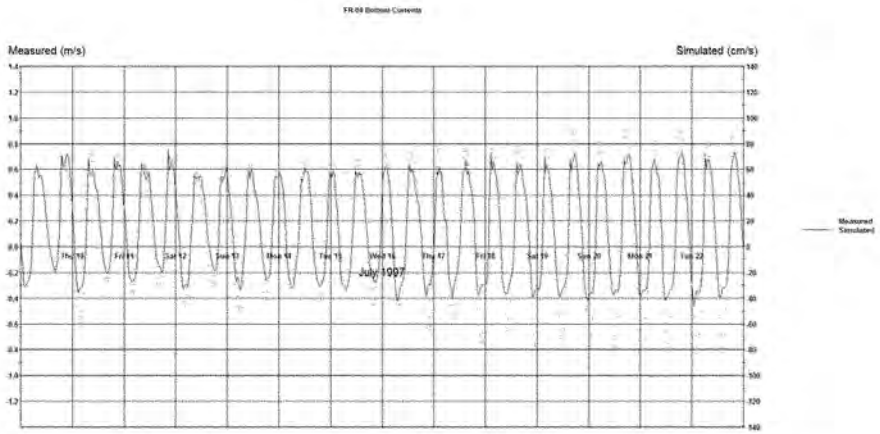


Figure E-11 Currents Comparison at FR-04 Bottom for July 9, 1997 through July 23, 1997



Figure E-12 Currents Comparison at FR-04 Bottom for July 24, 1997 through August 7, 1997

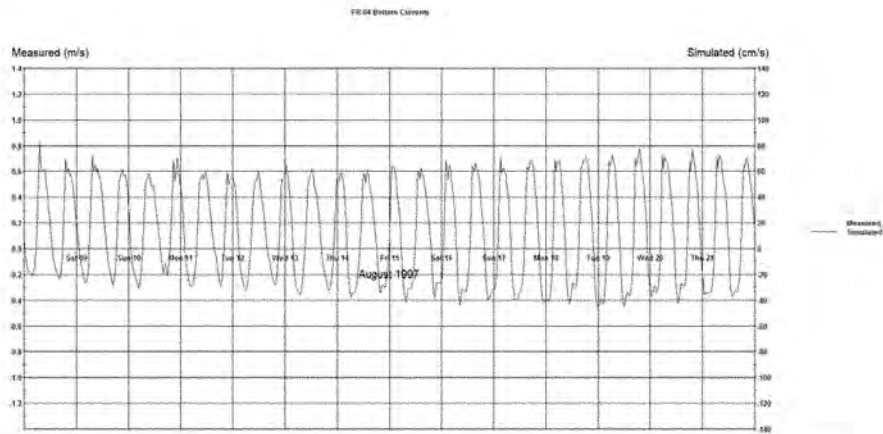


Figure E-13 Currents Comparison at FR-04 Bottom for August 8, 1997 through August 22, 1997



Figure E-14 Currents Comparison at FR-04 Bottom for August 23, 1997 through September 6, 1997

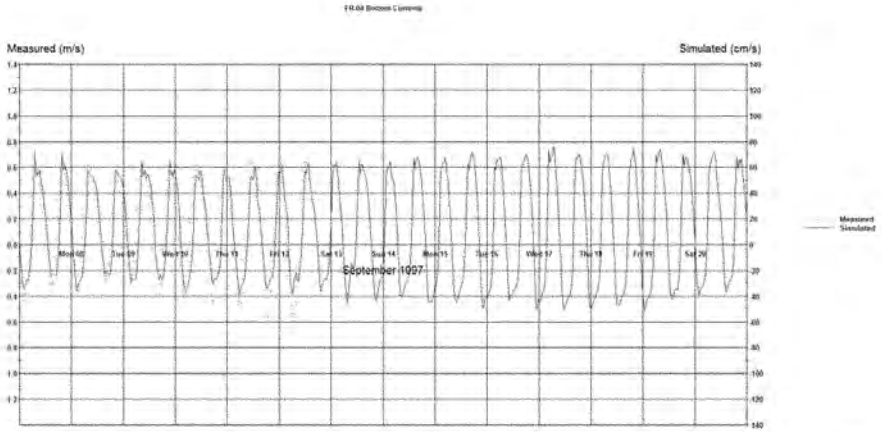


Figure E-15 Currents Comparison at FR-04 Bottom for September 7, 1997 through September 21, 1997

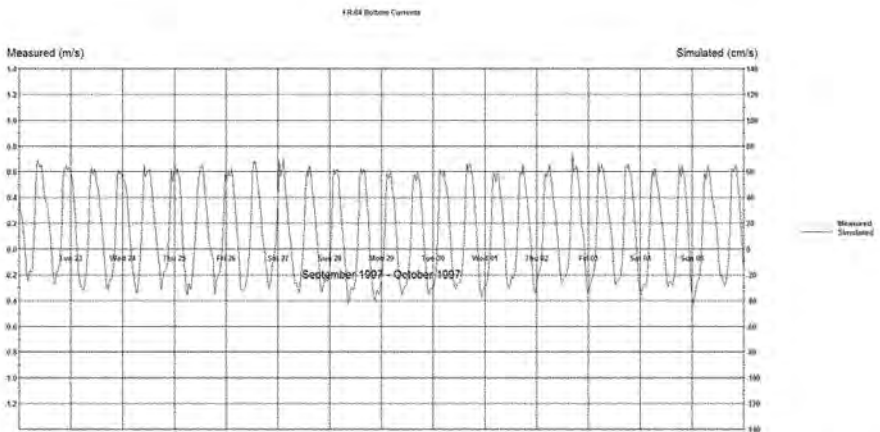


Figure E-16 Currents Comparison at FR-04 Bottom for September 22, 1997 through October 6, 1997

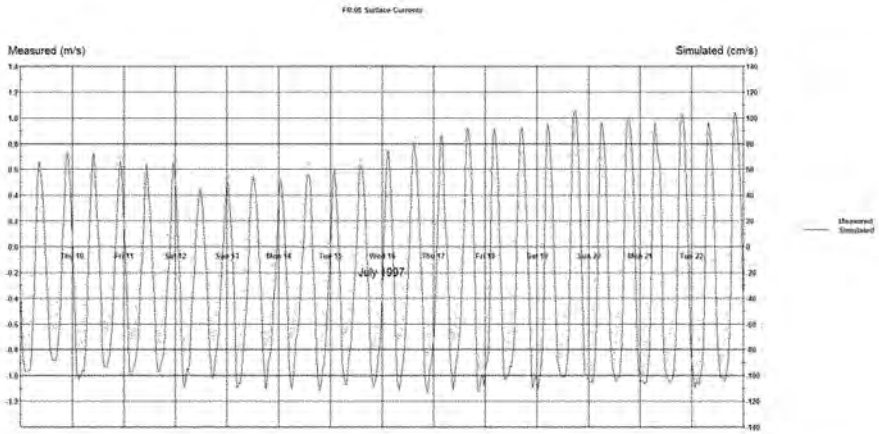


Figure E-17 Currents Comparison at FR-08 Surface for July 9, 1997 through July 23, 1997

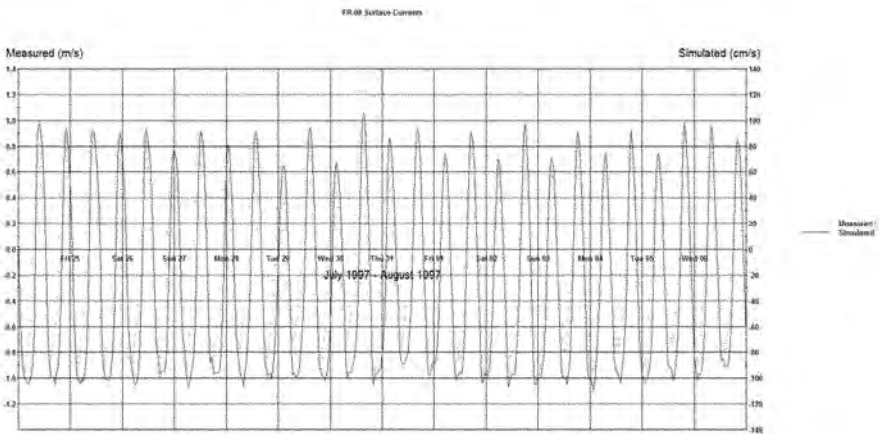


Figure E-18 Currents Comparison at FR-08 Surface for July 24, 1997 through August 7, 1997

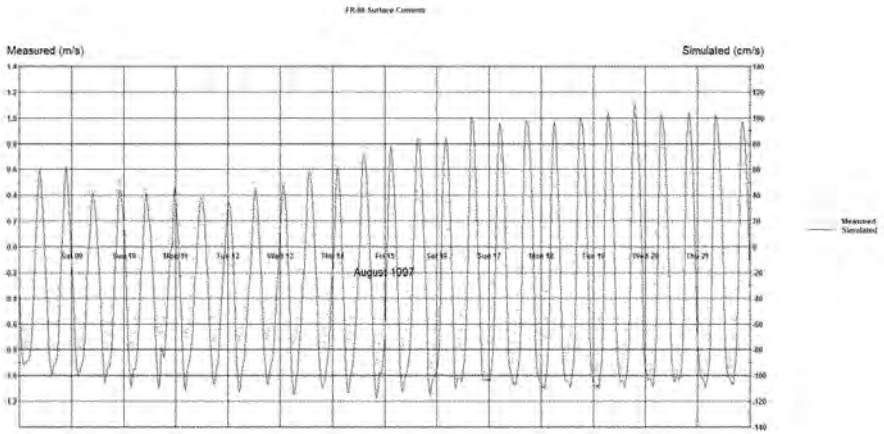


Figure E-19 Currents Comparison at FR-08 Surface for August 8, 1997 through August 22, 1997

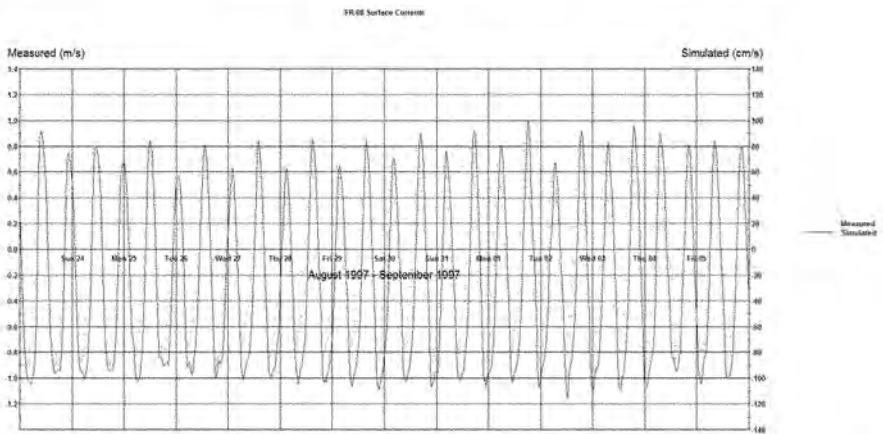


Figure E-20 Currents Comparison at FR-08 Surface for August 23, 1997 through September 6, 1997



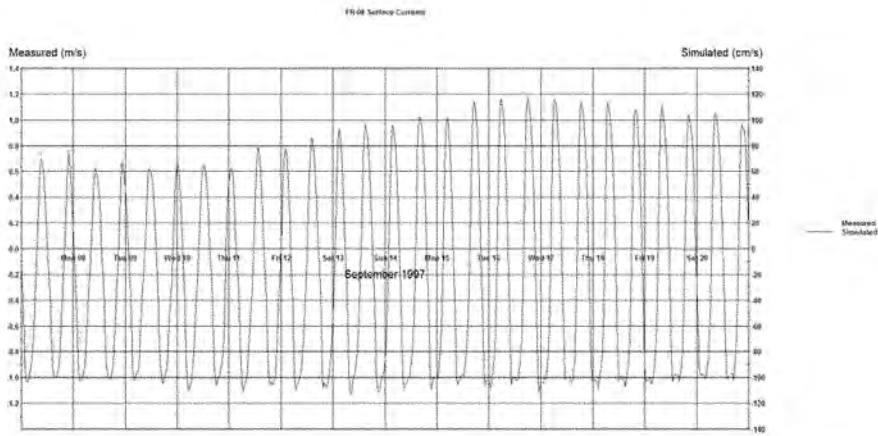


Figure E-21 Currents Comparison at FR-08 Surface for September 7, 1997 through September 21, 1997

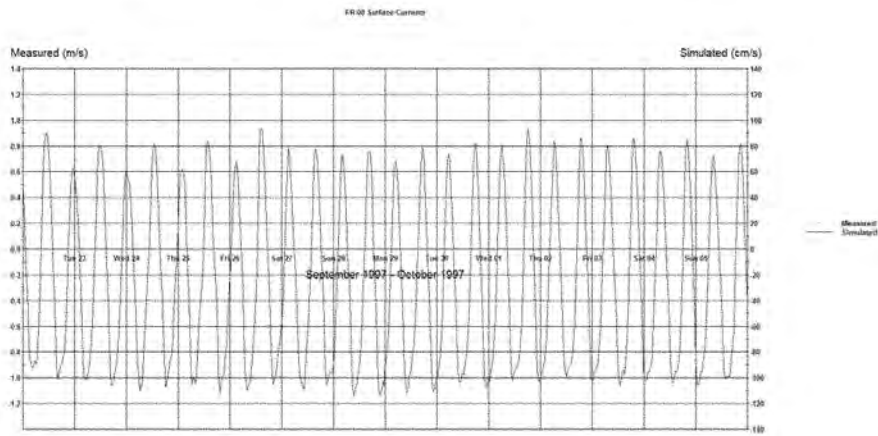


Figure E-22 Currents Comparison at FR-08 Surface for September 22, 1997 through October 6, 1997

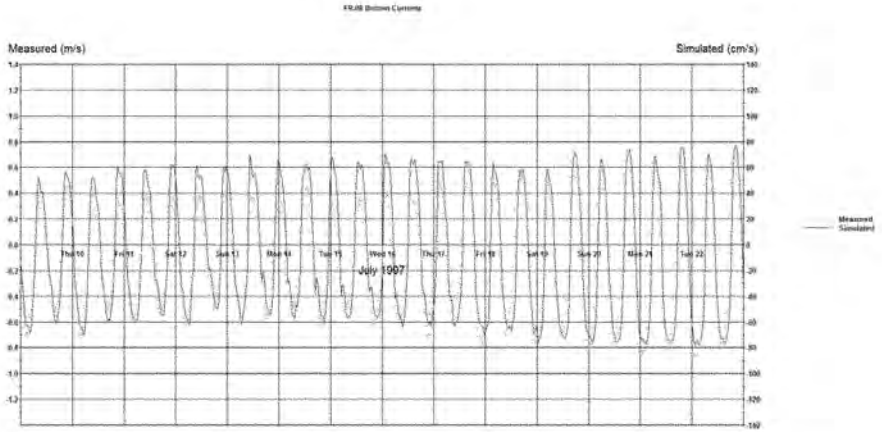


Figure E-23 Currents Comparison at FR-08 Bottom for July 9, 1997 through July 23, 1997

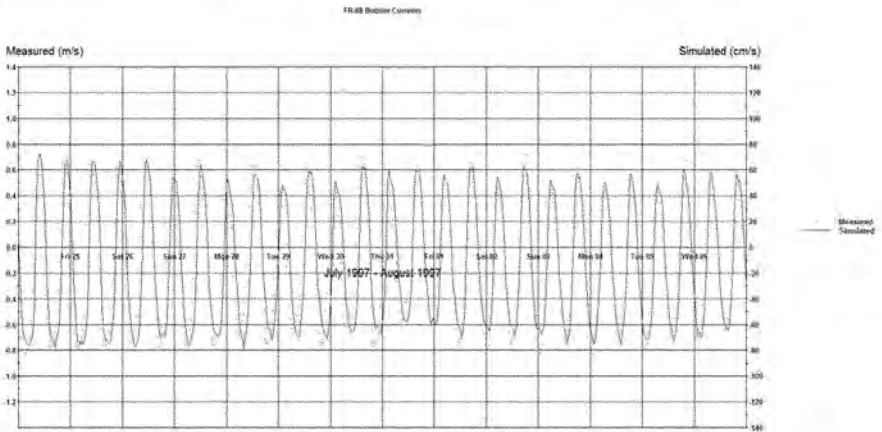


Figure E-24 Currents Comparison at FR-08 Bottom for July 24, 1997 through August 7, 1997

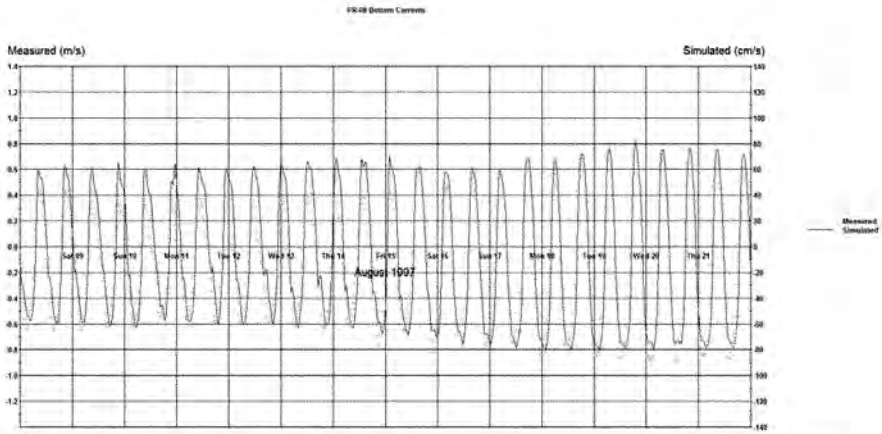


Figure E-25 Currents Comparison at FR-08 Bottom for August 8, 1997 through August 22, 1997

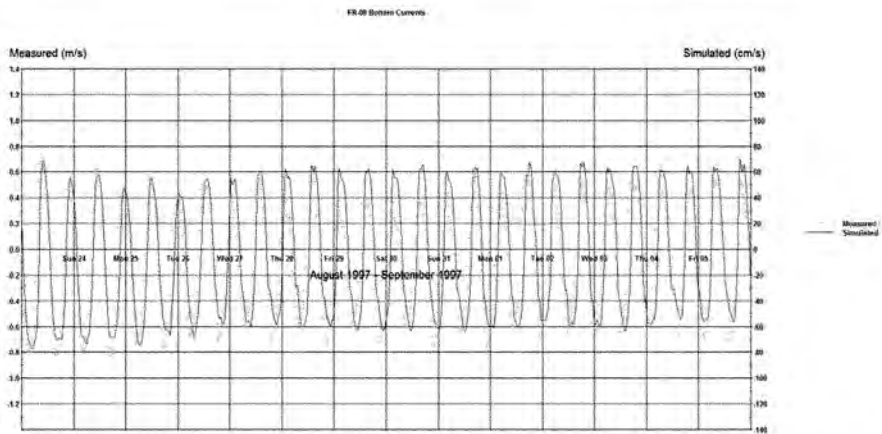


Figure E-26 Currents Comparison at FR-08 Bottom for August 23, 1997 through September 6, 1997

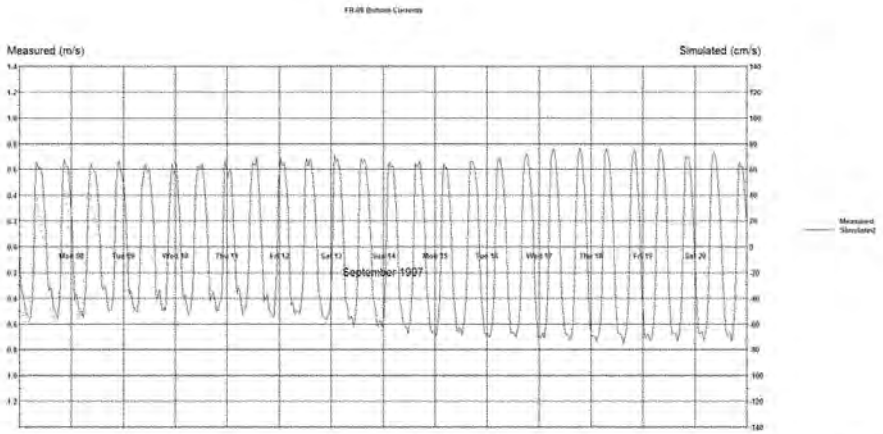


Figure E-27 Currents Comparison at FR-08 Bottom for September 7, 1997 through September 21, 1997

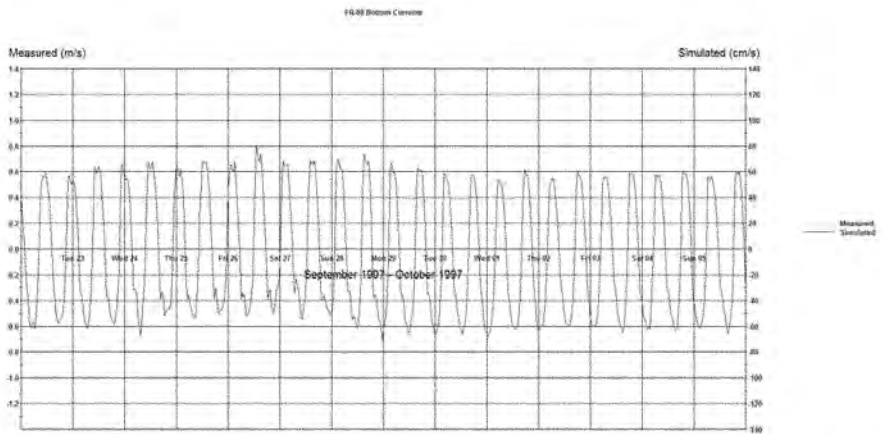


Figure E-28 Currents Comparison at FR-08 Bottom for September 22, 1997 through October 6, 1997

**APPENDIX F 1999 FLOW COMPARISONS**



Table F-1 1999 Flow Transect Locations and Julian Day

| Station    | I     | J   | 1999<br>Julian Day |
|------------|-------|-----|--------------------|
| FR2        | 13-15 | 96  | 964, 998, 1011     |
| MR2        | 26    | 96  | 964, 998, 1011     |
| LBR2       | 30    | 96  | 964, 998           |
| FR3        | 13-15 | 53  | 963, 999, 1010     |
| BR         | 30-32 | 60  | 963, 999, 1010     |
| FJ         | 13-17 | 49  | 963, 999, 1010     |
| FR1        | 13-15 | 118 | 1002, 1009         |
| MR1        | 26    | 120 | 1002, 1009         |
| LBR1       | 30    | 123 | 1002, 1009         |
| I95 -GPA14 | 13-14 | 126 | 1007               |
| FW1        | 33    | 123 | 1022, 1028         |
| FW2        | 39    | 114 | 1022, 1028         |
| FW3        | 30    | 109 | 1022, 1028         |
| FW4        | 30    | 92  | 1021, 1029         |
| FW5        | 30-31 | 76  | 1021, 1029         |
| FW6        | 30-32 | 71  | 1021, 1029         |
| MC         | 19    | 123 | 1002, 1009         |
| UC         | 23    | 125 | 1002, 1009         |

Table F-2 1999 Flow Statistical Comparison

| Transect Location | Julian Day 1997 | Date         | 1999 Flow Comparisons (m <sup>3</sup> /s) |          |           |          |                |                  |
|-------------------|-----------------|--------------|-------------------------------------------|----------|-----------|----------|----------------|------------------|
|                   |                 |              | Peak Flood                                |          | Peak Ebb  |          | Ebb Difference | Flood Difference |
|                   |                 |              | Simulated                                 | Measured | Simulated | Measured |                |                  |
| FJ                | 963             | August 21    | 2,989                                     | 2,850    |           |          |                | 5%               |
|                   | 999             | September 26 |                                           |          | -3,380    | -5,060   | -33%           |                  |
|                   | 1010            | October 07   |                                           |          | -3,343    | -4,678   | -29%           |                  |
| FR3               | 963             | August 21    | 1,738                                     | 1,744    |           |          |                | 0%               |
|                   | 999             | September 26 |                                           |          | -2,402    | -2,951   | -19%           |                  |
|                   | 1010            | October 07   |                                           |          | -2,090    | -2,755   | -24%           |                  |
| BR                | 963             | August 21    | 1,033                                     | 1,037    |           |          |                | 0%               |
|                   | 999             | September 26 |                                           |          | -1,049    | -1,543   | -32%           |                  |
|                   | 1010            | October 07   |                                           |          | -1,219    | -1,558   | -22%           |                  |
| FR2               | 964             | August 22    |                                           |          | -694      | -918     | -24%           |                  |
|                   | 998             | September 25 |                                           |          | -1,065    | -1,460   | -27%           |                  |
|                   | 1011            | October 08   |                                           |          | -1,064    | -1,505   | -29%           |                  |
| MR2               | 964             | August 22    | 208                                       | 163      | -167      | -181     | -8%            | 26%              |
|                   | 998             | September 25 |                                           |          | -250      | -467     | -46%           |                  |
|                   | 1011            | October 08   |                                           |          | -241      | -490     | -51%           |                  |
| LBR2              | 964             | August 22    | 107                                       | 110      | -120      | -144     | -17%           | -3%              |
|                   | 998             | September 25 |                                           |          | -155      | -241     | -36%           |                  |
|                   | 1002            | September 29 |                                           |          | -684      | -873     | -22%           |                  |
| FR1               | 1009            | October 06   | 841                                       | 651      | -625      | -942     | -34%           | -2%              |
|                   | 1002            | September 29 |                                           |          | -130      | -126     | 3%             |                  |
| MR1               | 1009            | October 06   | 95                                        | 94       |           |          |                | 1%               |
|                   | 1002            | September 29 | 2                                         | 45       |           |          |                | -96%             |
|                   | 1009            | October 06   |                                           |          | -38       | -55      | -31%           |                  |
| I-95              | 1007            | October 04   | 362                                       | 434      | -448      | -687     | -35%           | -17%             |
|                   | 1022            | October 19   | 0                                         | 7        | -17       | -43      | -60%           | -100%            |
|                   | 1028            | October 25   | 10                                        | 42       | -39       | -74      | -47%           | -76%             |
| FW2               | 1022            | October 19   | 95                                        | 67       | -60       | -101     | -41%           | 42%              |
|                   | 1028            | October 25   | 130                                       | 108      | -71       | -188     | -62%           | 20%              |
|                   | 1022            | October 19   | 162                                       | 102      | -87       | -158     | -45%           | 59%              |
| FW3               | 1028            | October 25   | 190                                       | 143      | -128      | -247     | -48%           | 33%              |
|                   | 1021            | October 18   | 58                                        | 162      | -117      | -209     | -44%           | -64%             |
|                   | 1029            | October 26   | 232                                       | 245      | -174      | -347     | -50%           | -5%              |
| FW4               | 1021            | October 18   | 388                                       | 385      | -313      | -347     | -10%           | 1%               |
|                   | 1029            | October 26   | 644                                       | 648      | -418      | -804     | -48%           | -1%              |
|                   | 1021            | October 18   | 463                                       | 552      | -363      | -486     | -25%           | -16%             |
| MC                | 272             | September 29 | 111                                       | 137      |           |          |                | -19%             |
|                   | 279             | 6-Oct        | 106                                       | 106      | -100      | -165     | -40%           | 0%               |
| UC                | 272             | September 29 |                                           |          | -106      | -175     | -39%           |                  |
|                   | 279             | 6-Oct        | 156                                       | 101      | -100      | -173     | -42%           | 54%              |

NOTES: [ ] = Determined to be insufficient data to determine peak



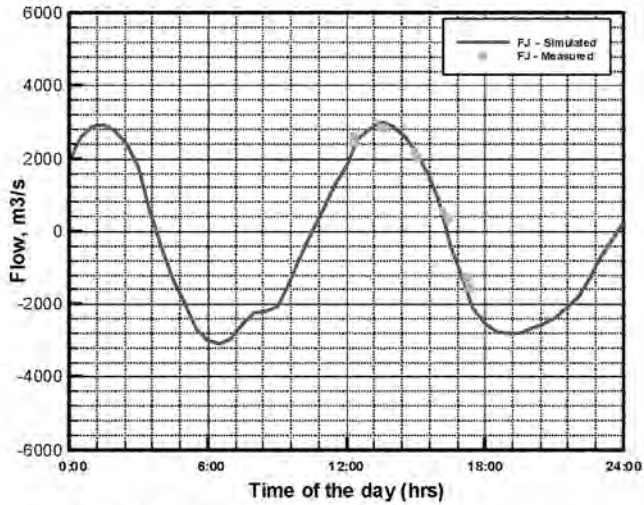


Figure F-1 Flow (m<sup>3</sup>/s) at Transect FJ on August 21, 1999

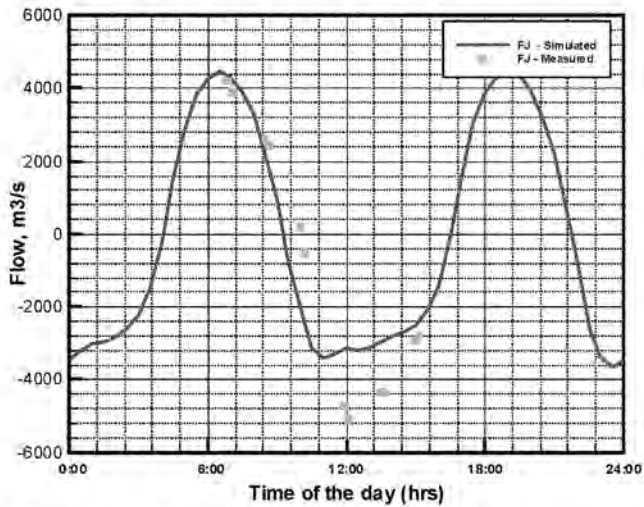


Figure F-2 Flow (m<sup>3</sup>/s) at Transect FJ on September 26, 1999

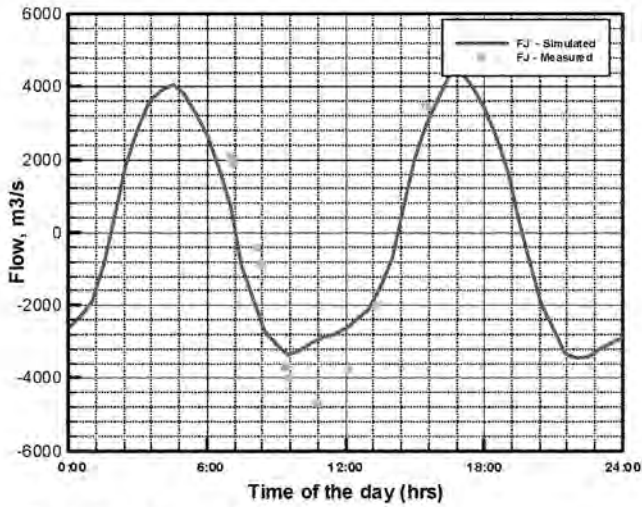


Figure F-3 Flow (m<sup>3</sup>/s) at Transect FJ on October 7, 1999

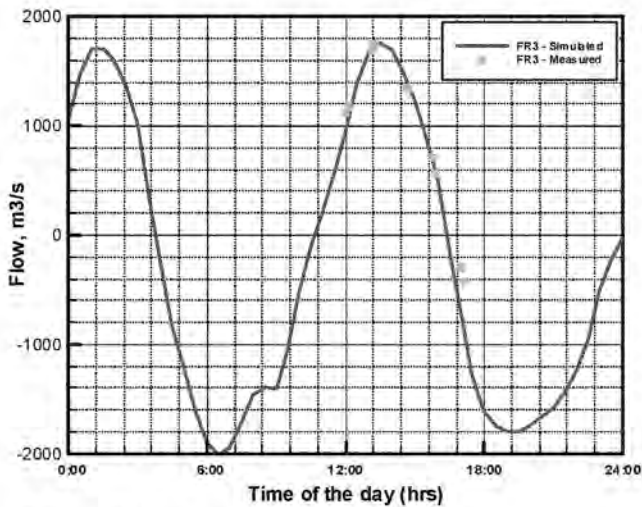


Figure F-4 Flow (m<sup>3</sup>/s) at Transect FR3 on August 21, 1999

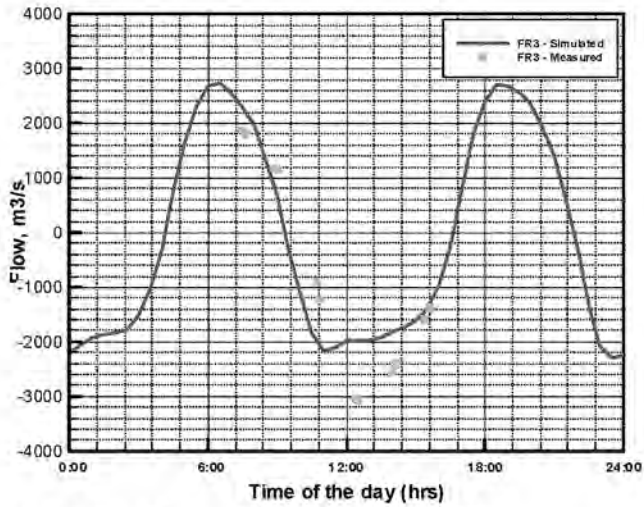


Figure F-5 Flow (m<sup>3</sup>/s) at Transect FR3 on September 26, 1999

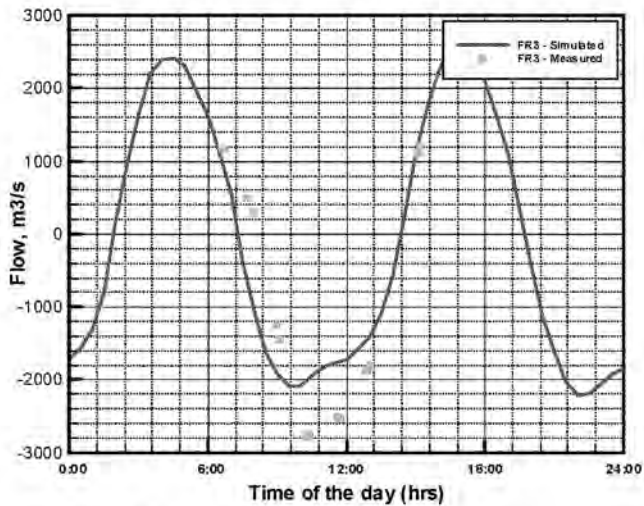


Figure F-6 Flow (m<sup>3</sup>/s) at Transect FR3 on October 7, 1999

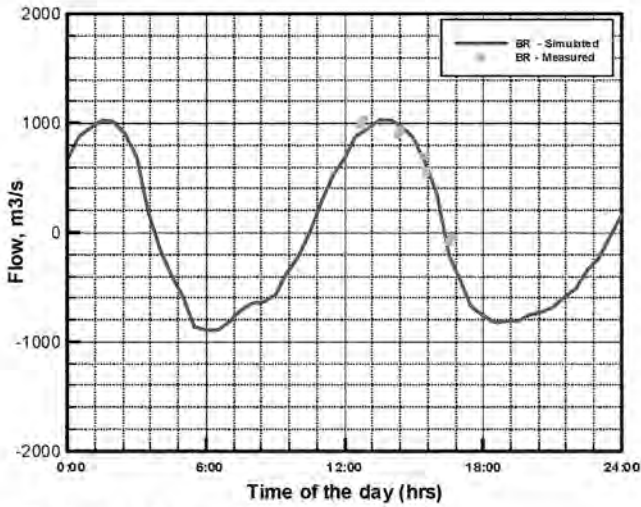


Figure F-7 Flow (m<sup>3</sup>/s) at Transect BR on August 21, 1999

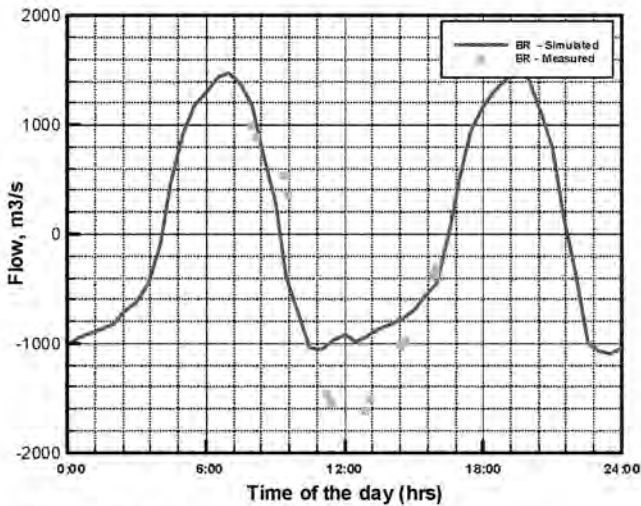


Figure F-8 Flow (m<sup>3</sup>/s) at Transect BR on September 26, 1999

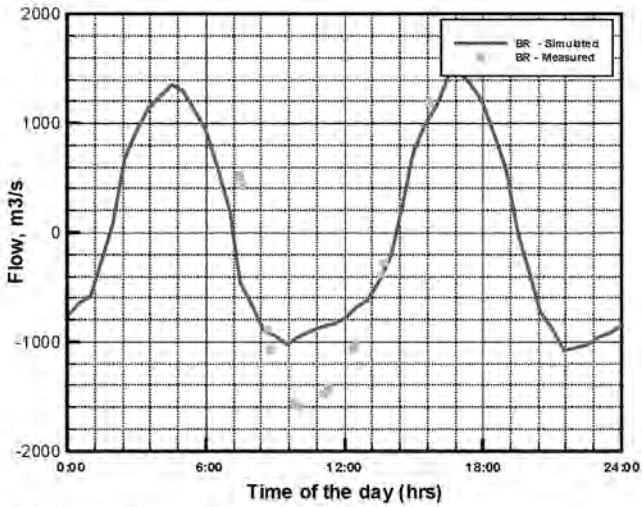


Figure F-9 Flow (m<sup>3</sup>/s) at Transect BR on October 7, 1999

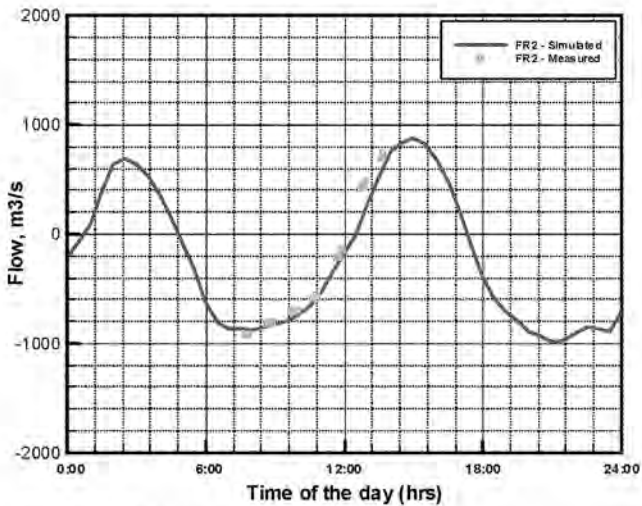


Figure F-10 Flow (m<sup>3</sup>/s) at Transect FR2 on August 22, 1999

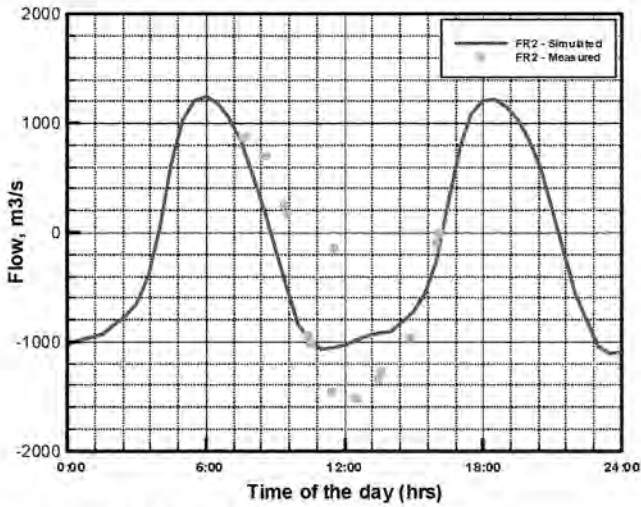


Figure F-11 Flow (m<sup>3</sup>/s) at Transect FR2 on September 25, 1999

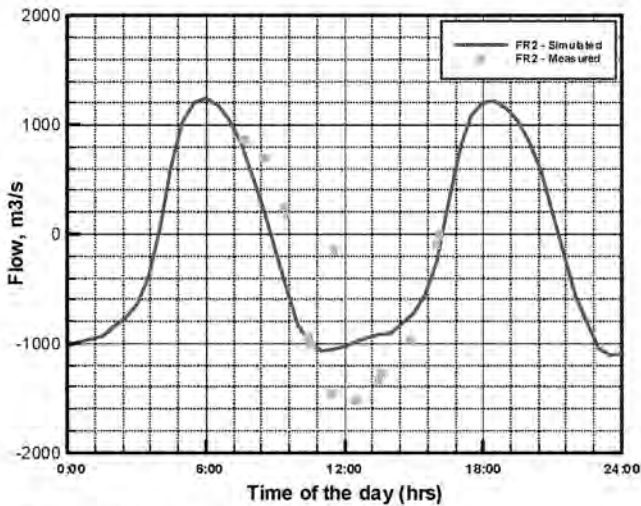


Figure F-12 Flow (m<sup>3</sup>/s) at Transect FR2 on October 8, 1999

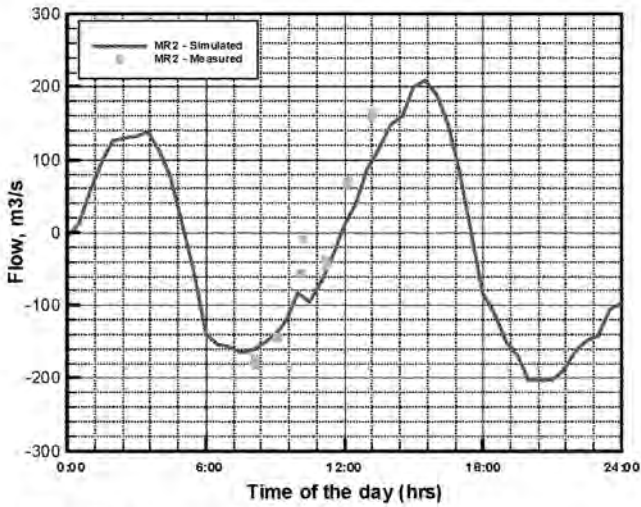


Figure F-13 Flow (m<sup>3</sup>/s) at Transect MR2 on August 22, 1999

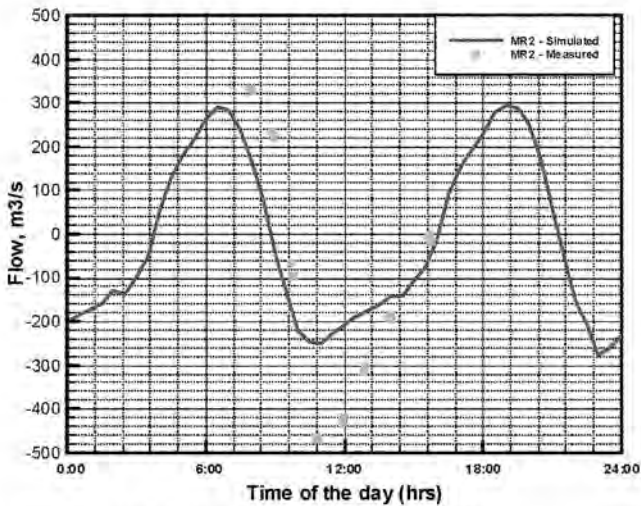


Figure F-14 Flow (m<sup>3</sup>/s) at Transect MR2 on September 25, 1999

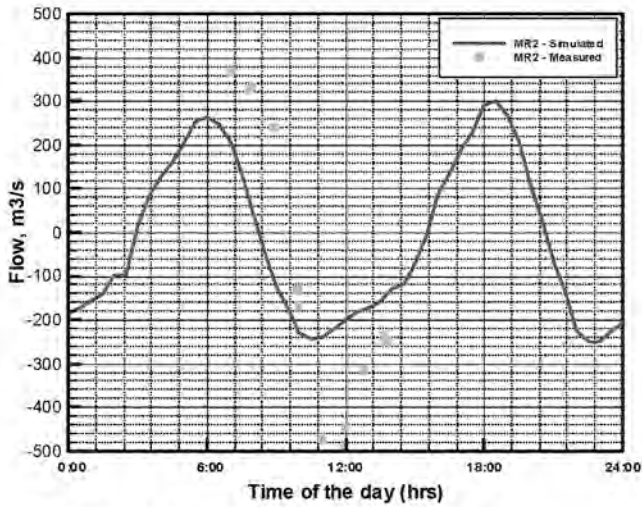


Figure F-15 Flow (m<sup>3</sup>/s) at Transect MR2 on October 8, 1999

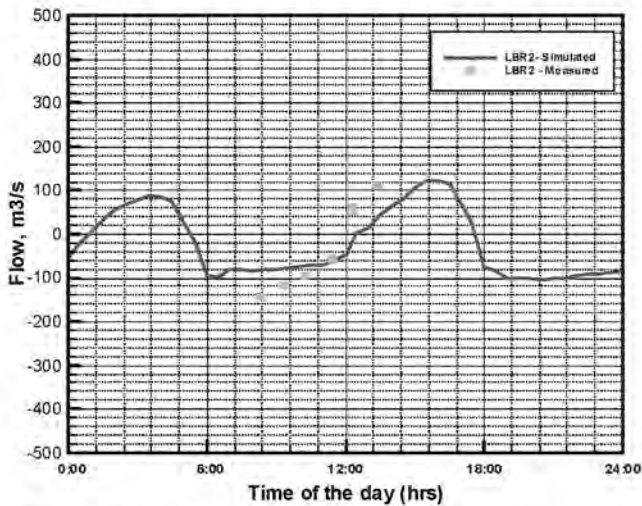


Figure F-16 Flow (m<sup>3</sup>/s) at Transect LBR2 on August 22, 1999



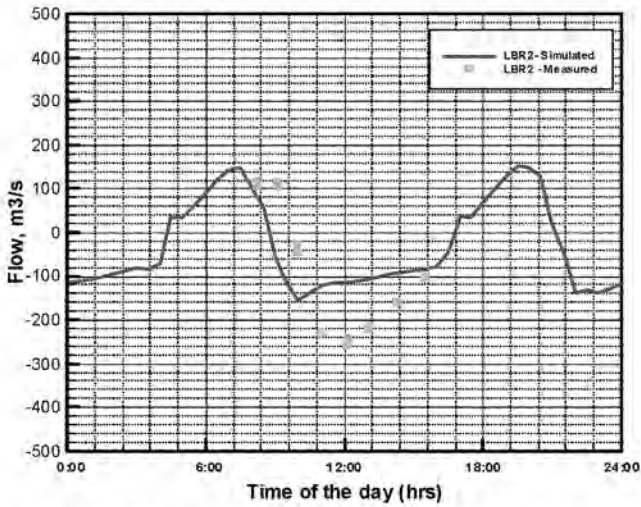


Figure F-17 Flow (m<sup>3</sup>/s) at Transect LBR2 on September 25, 1999

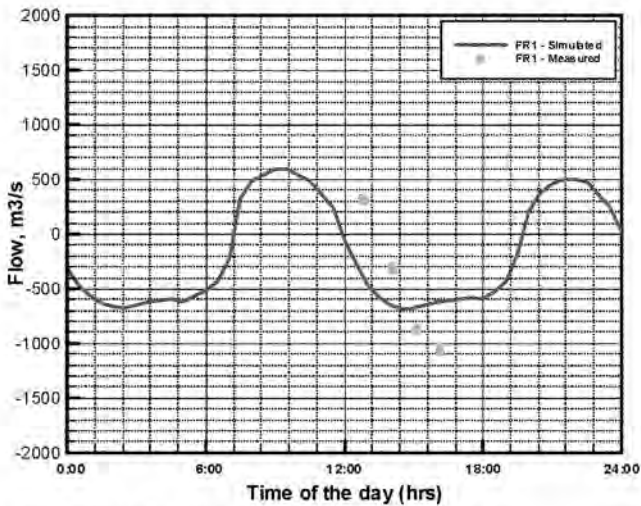


Figure F-18 Flow (m<sup>3</sup>/s) at Transect FR1 on September 29, 1999

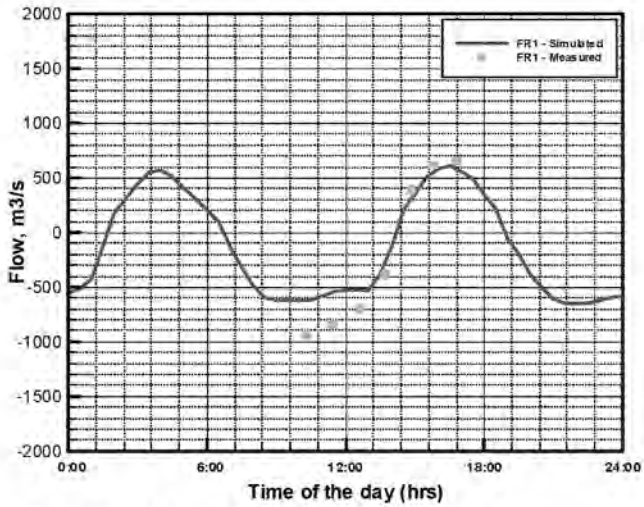


Figure F-19 Flow (m<sup>3</sup>/s) at Transect FR1 on October 6, 1999

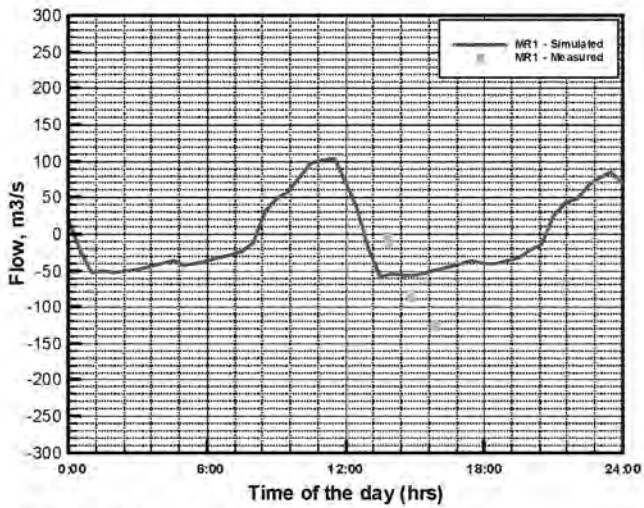


Figure F-20 Flow (m<sup>3</sup>/s) at Transect MR1 on September 29, 1999

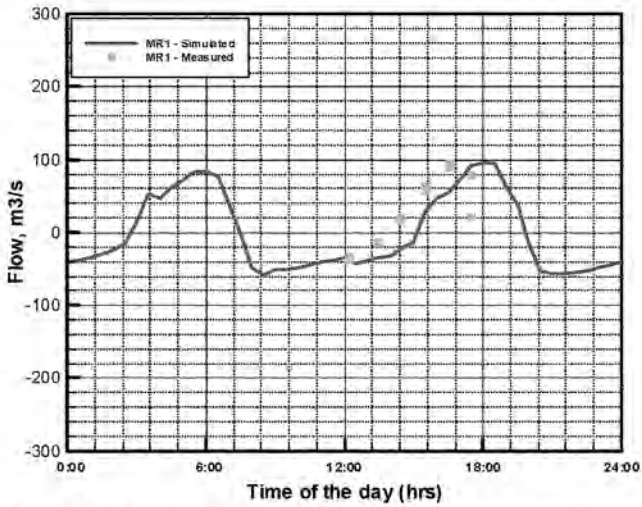


Figure F-21 Flow (m<sup>3</sup>/s) at Transect MR1 on October 6, 1999

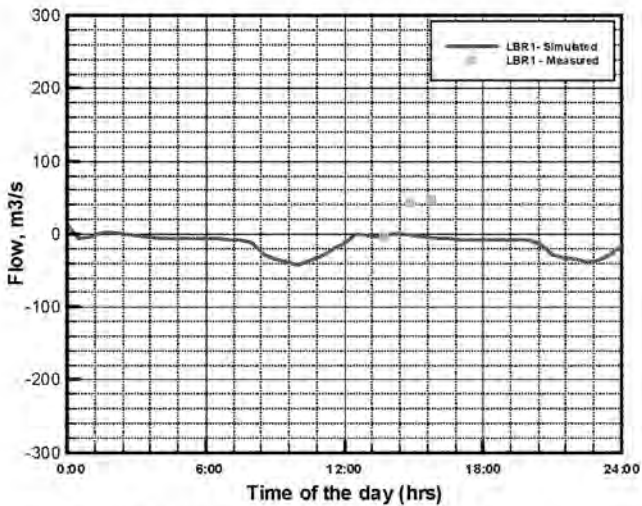


Figure F-22 Flow (m<sup>3</sup>/s) at Transect LBR1 on September 29, 1999

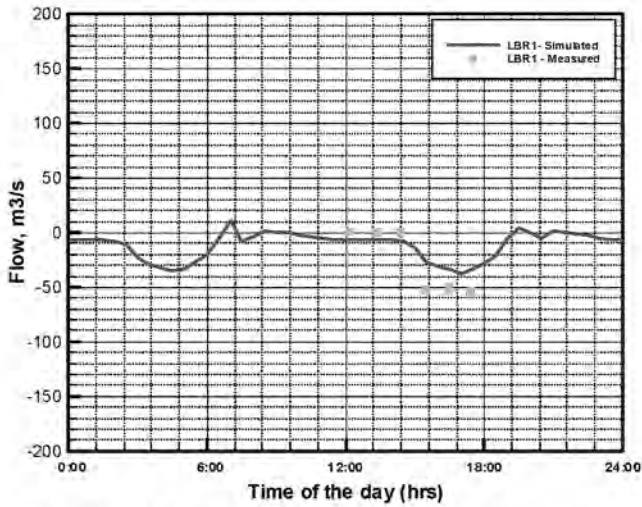


Figure F-23 Flow (m<sup>3</sup>/s) at Transect LBR1 on October 6, 1999

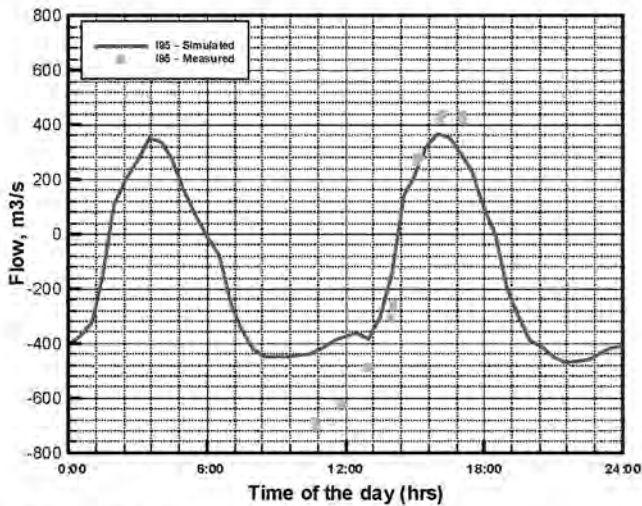


Figure F-24 Flow (m<sup>3</sup>/s) at Transect I-95 on October 4, 1999

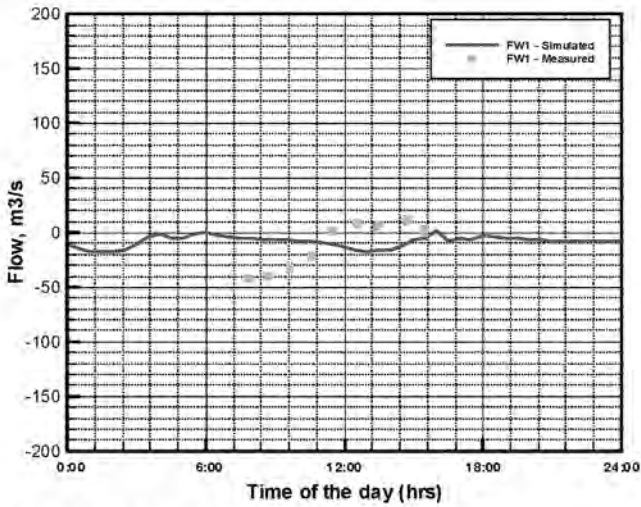


Figure F-25 Flow (m<sup>3</sup>/s) at Transect FW1 on October 19, 1999

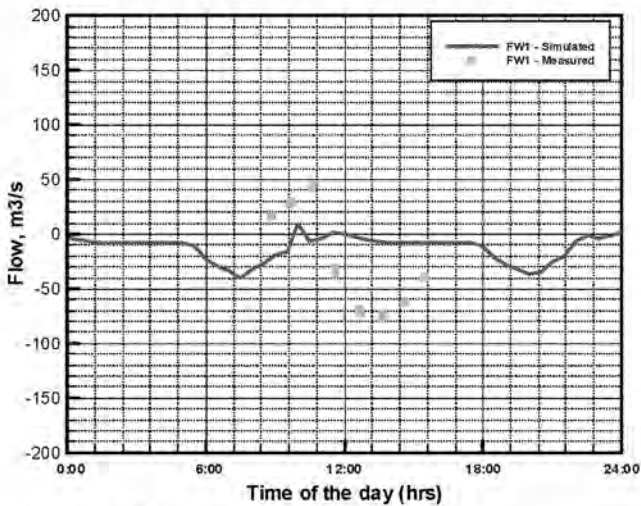


Figure F-26 Flow (m<sup>3</sup>/s) at Transect FW1 on October 25, 1999

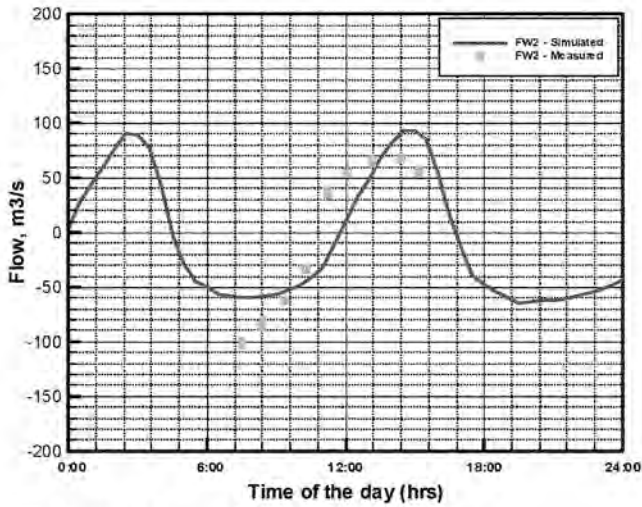


Figure F-27 Flow (m<sup>3</sup>/s) at Transect FW2 on October 19, 1999

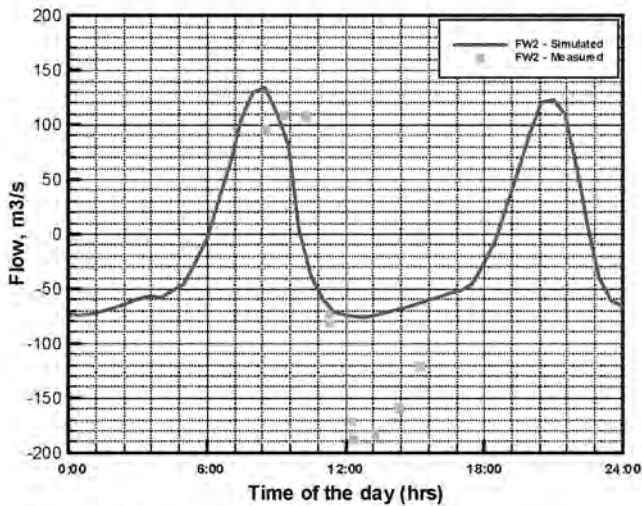


Figure F-28 Flow (m<sup>3</sup>/s) at Transect FW2 on October 25, 1999

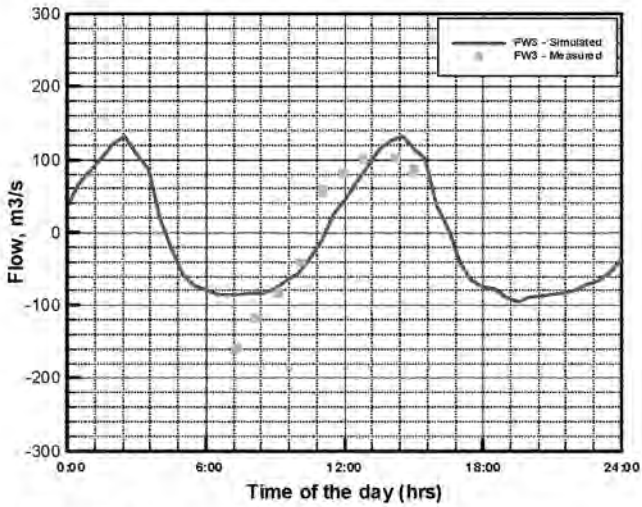


Figure F-29 Flow (m<sup>3</sup>/s) at Transect FW3 on October 19, 1999

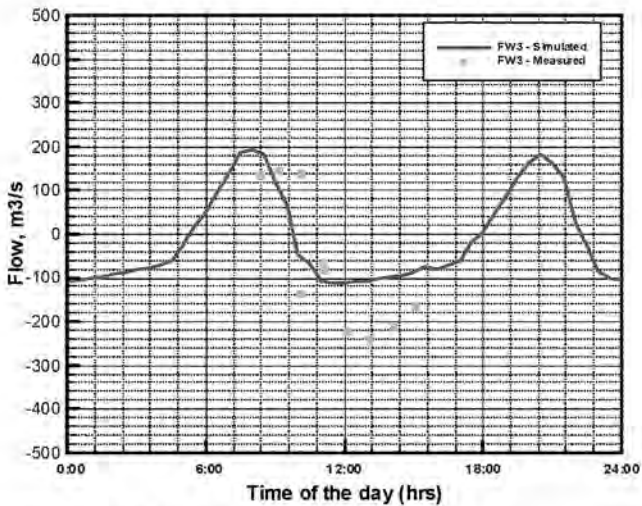


Figure F-30 Flow (m<sup>3</sup>/s) at Transect FW3 on October 25, 1999

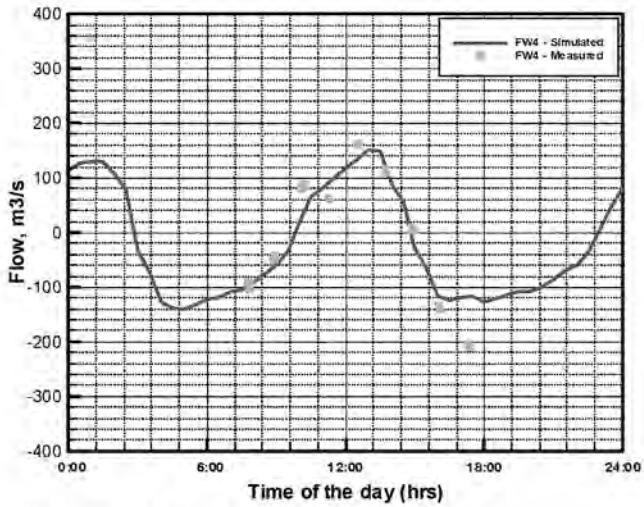


Figure F-31 Flow (m<sup>3</sup>/s) at Transect FW4 on October 18, 1999

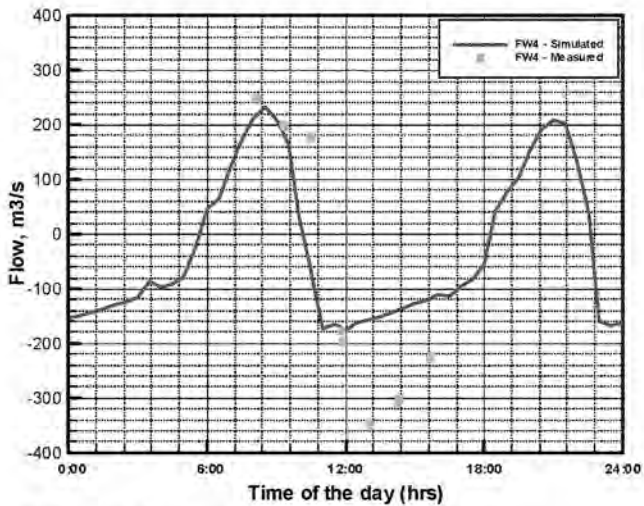


Figure F-32 Flow (m<sup>3</sup>/s) at Transect FW4 on October 26, 1999



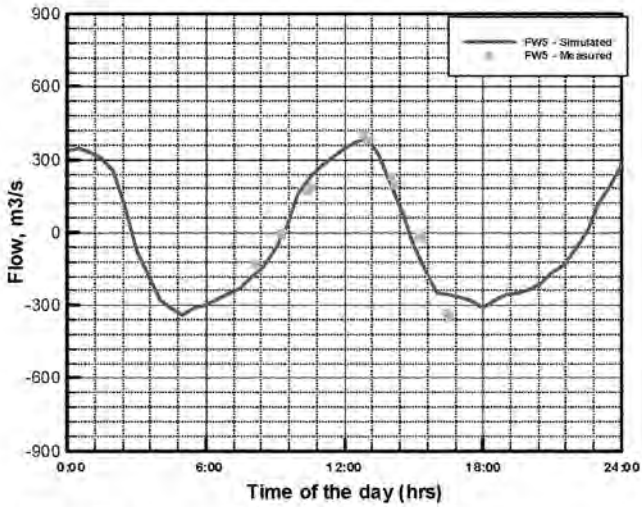


Figure F-33 Flow (m<sup>3</sup>/s) at Transect FW5 on October 18, 1999

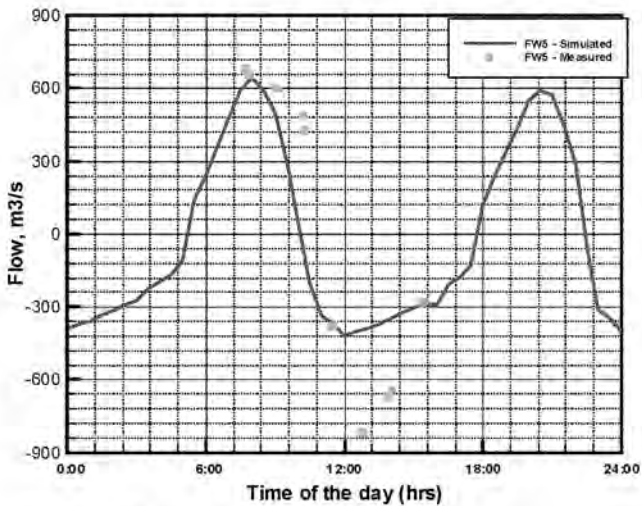


Figure F-34 Flow (m<sup>3</sup>/s) at Transect FW5 on October 26, 1999

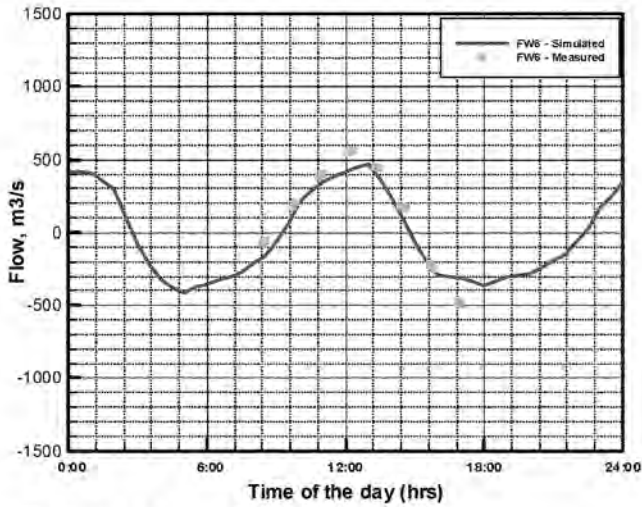


Figure F-35 Flow (m<sup>3</sup>/s) at Transect FW6 on October 18, 1999

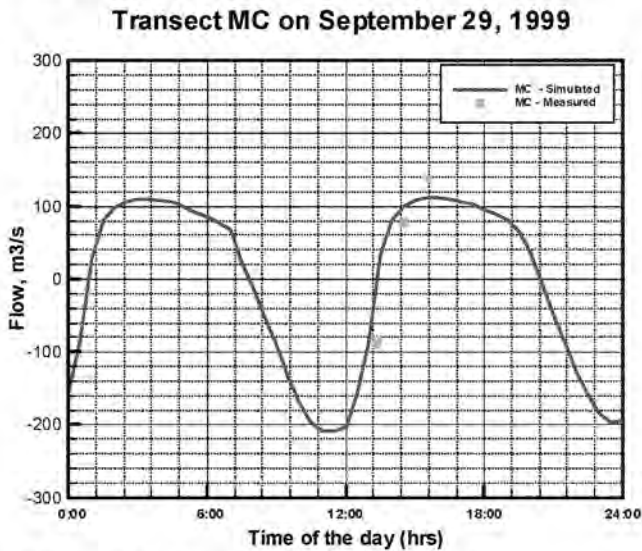


Figure F-36 Flow (m<sup>3</sup>/s) at Transect MC on September 29, 1999

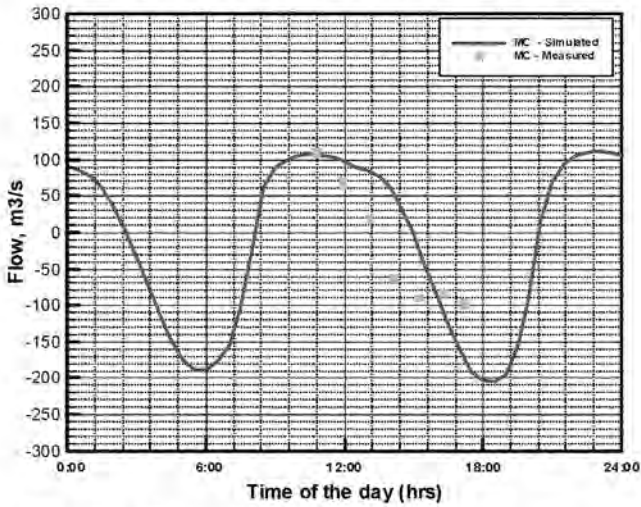
**Transect MC on October 6, 1999**

Figure F-37 Flow (m<sup>3</sup>/s) at Transect MC on October 6, 1999

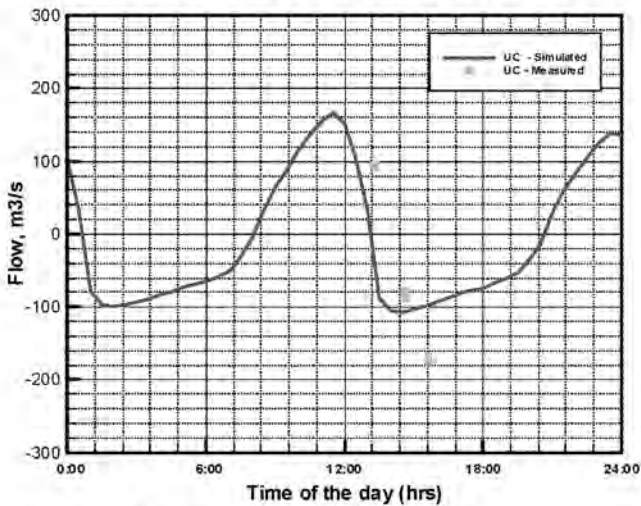
**Transect UC on September 29, 1999**

Figure F-38 Flow (m<sup>3</sup>/s) at Transect UC on September 29, 1999

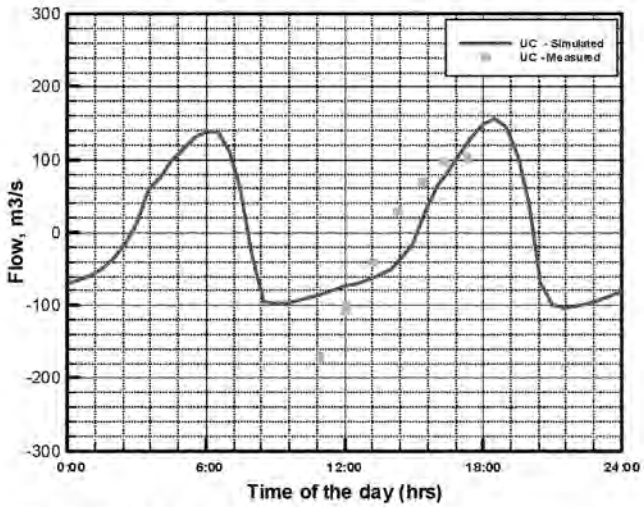
**Transect UC on October 6, 1999**

Figure F-39 Flow (m<sup>3</sup>/s) at Transect UC on October 18, 1999

**APPENDIX G 1997 FLOW COMPARISONS**



Table G-1 1997 Flow Transect Locations and Julian Day

| Station | I     | J   | 1997<br>Julian Day |
|---------|-------|-----|--------------------|
| FR2     | 13-15 | 96  | 273                |
| MR2     | 26    | 96  | 273                |
| LBR2    | 30    | 96  | 273                |
| FR3     | 13-15 | 53  | 253, 280           |
| BR      | 30-32 | 60  | 253, 280           |
| FJ      | 13-17 | 49  | 253, 276, 280      |
| FR1     | 13-15 | 118 | 279                |
| MR1     | 26    | 120 | 279                |
| LBR1    | 30    | 123 | 279                |
| I95     | 13-14 | 126 | 254, 279           |
| MC      | 19    | 123 | 279                |
| UC      | 23    | 125 | 279                |

Table G-2 1997 Flow Statistical Comparisons

| 1997 Flow Comparisons (m <sup>3</sup> /s) |                 |              |            |          |           |          |                |                  |
|-------------------------------------------|-----------------|--------------|------------|----------|-----------|----------|----------------|------------------|
| Transect Location                         | Julian Day 1997 | Date         | Peak Flood |          | Peak Ebb  |          | Ebb Difference | Flood Difference |
|                                           |                 |              | Simulated  | Measured | Simulated | Measured |                |                  |
| FJ                                        | 253             | September 10 | 3,052      | 2,666    | -2,938    | -3,720   | -21%           | 14%              |
|                                           | 276             | October 03   |            |          | -3,250    | -4,386   | -26%           |                  |
|                                           | 280             | October 07   | 3,170      | 3,102    |           |          |                | 2%               |
| FR3                                       | 253             | September 10 | 1,841      | 1,650    |           |          |                | 12%              |
|                                           | 280             | October 07   | 1,916      | 1,551    |           |          |                | 24%              |
| BR                                        | 253             | September 10 | 1,022      | 1,050    |           |          |                | -3%              |
|                                           | 280             | October 07   | 1,057      | 1,101    |           |          |                | -4%              |
| FR2                                       | 273             | September 30 | 983        | 849      | -989      | -1,076   | -8%            | 16%              |
| MR2                                       | 273             | September 30 | 234        | 300      | -183      | -248     | -26%           | -22%             |
| LBR2                                      | 273             | September 30 | 105        | 130      | -100      | -192     | -48%           | -19%             |
| FR1                                       | 279             | October 06   | 407        | 352      | -660      | -661     | 0%             | 16%              |
| MR1                                       | 279             | October 06   | 61         | 40       | -50       | -65      | -23%           | 53%              |
| LBR1                                      | 279             | October 06   | -6         | -8       | -30       | -45      | -33%           | -25%             |
| I-95                                      | 254             | September 11 | 411        | 229      |           |          |                | 79%              |
|                                           | 279             | October 06   | 224        | 230      | -509      | -561     | -9%            | -3%              |
| MC                                        | 279             | October 06   | 25         | 85       | -149      | -88      | 69%            | -71%             |
| UC                                        | 279             | October 06   | 102        | 60       | -76       | -80      | -5%            | 70%              |

NOTES:   = Determined to be insufficient data to determine peak



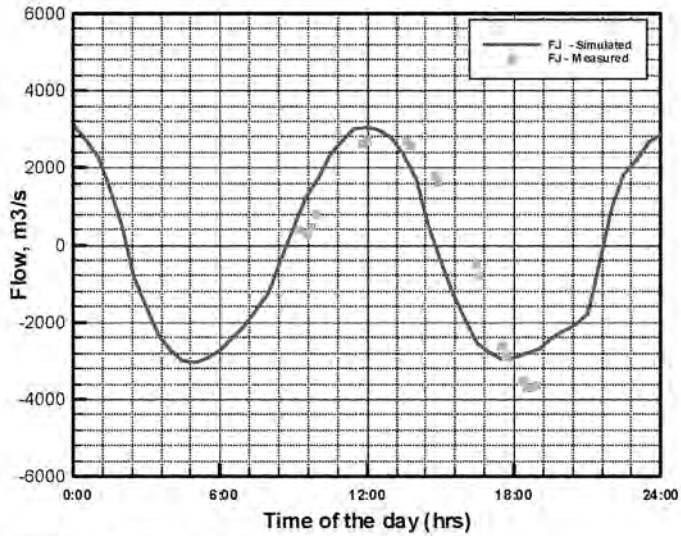


Figure G-1 Flow (m<sup>3</sup>/s) at Transect FJ on September 10, 1997

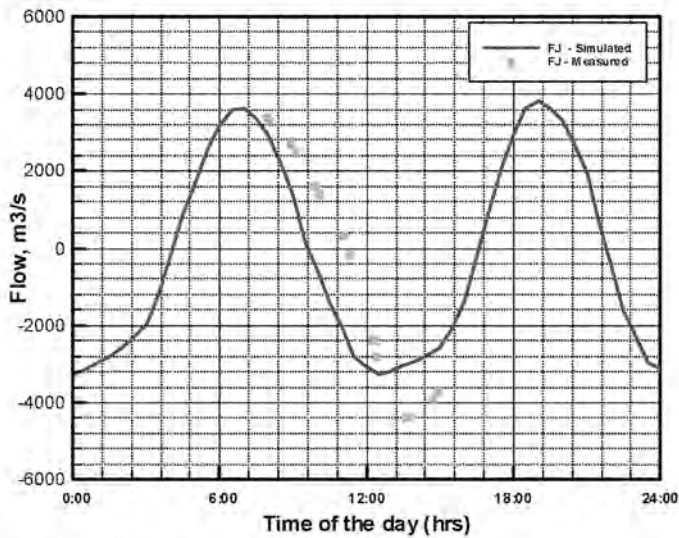


Figure G-2 Flow (m<sup>3</sup>/s) at Transect FJ on October 3, 1997

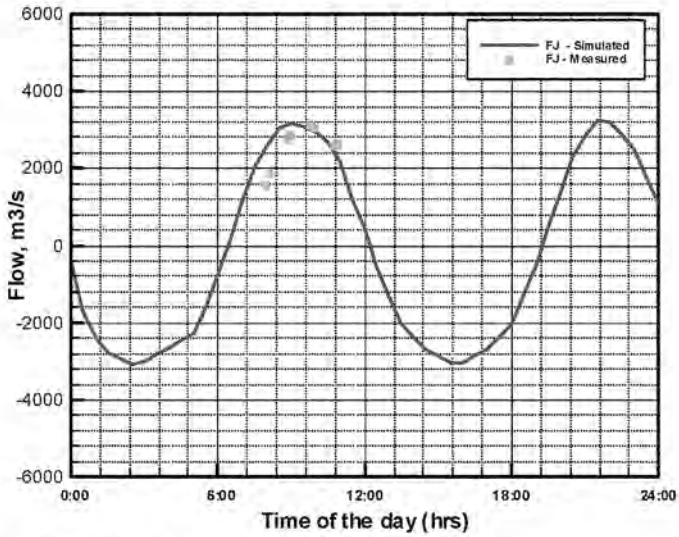


Figure G-3 Flow (m<sup>3</sup>/s) at Transect FJ on October 7, 1997

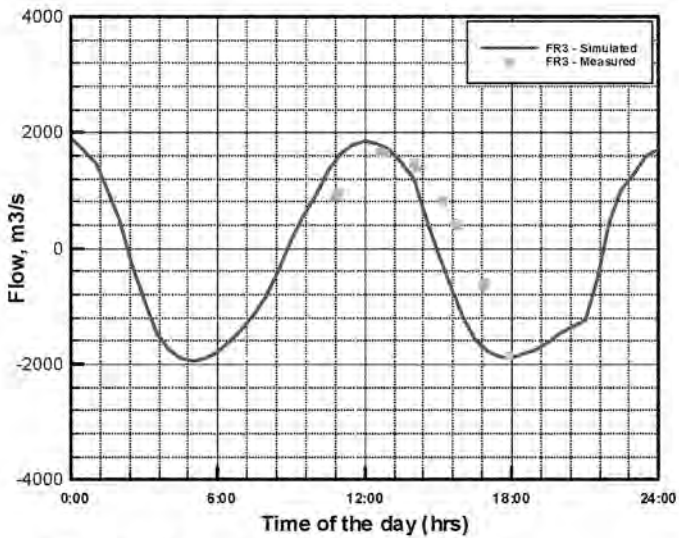


Figure G-4 Flow (m<sup>3</sup>/s) at Transect FR3 on September 10, 1997

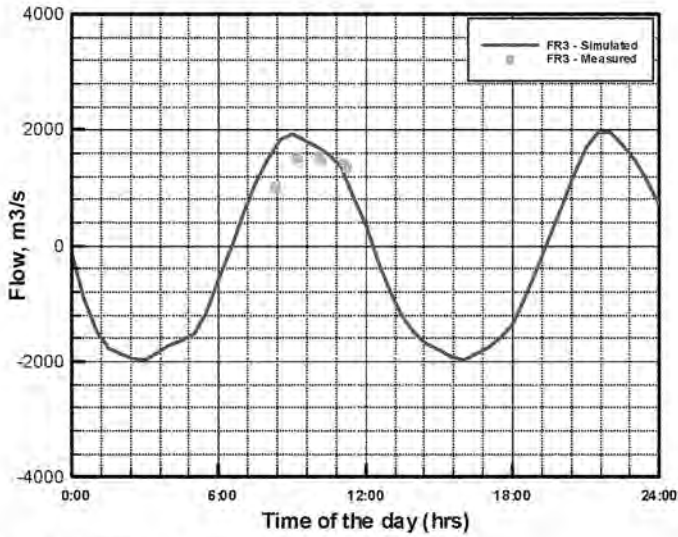


Figure G-5 Flow (m<sup>3</sup>/s) at Transect FR3 on October 7, 1997

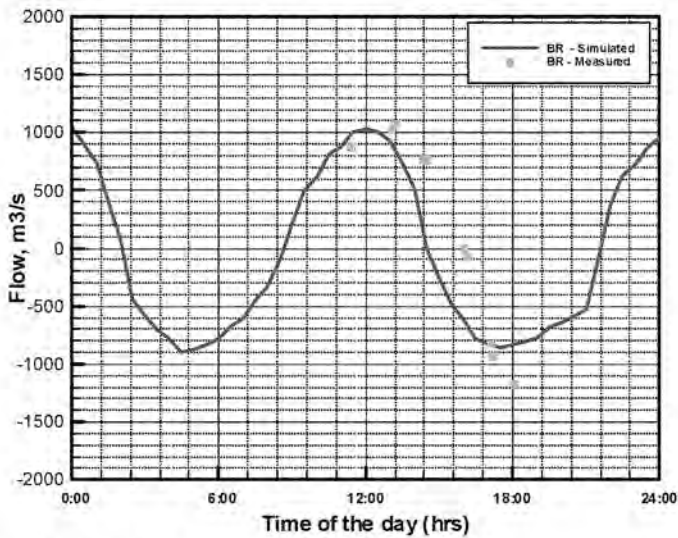


Figure G-6 Flow (m<sup>3</sup>/s) at Transect BR on September 10, 1997

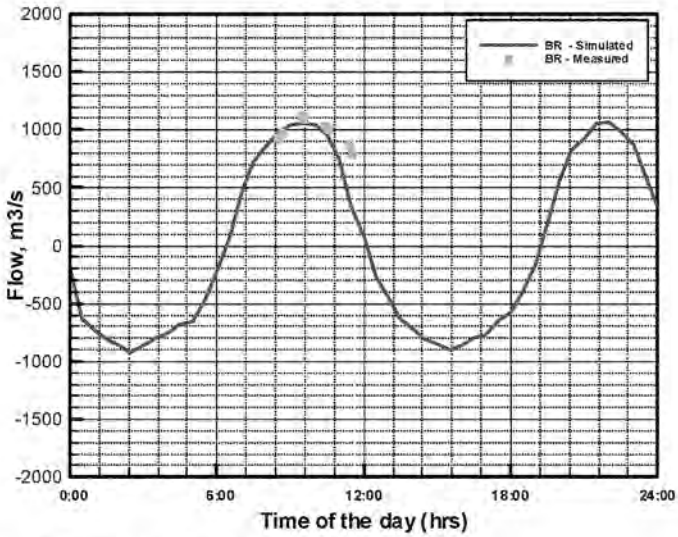


Figure G-7 Flow (m<sup>3</sup>/s) at Transect BR on October 7, 1997

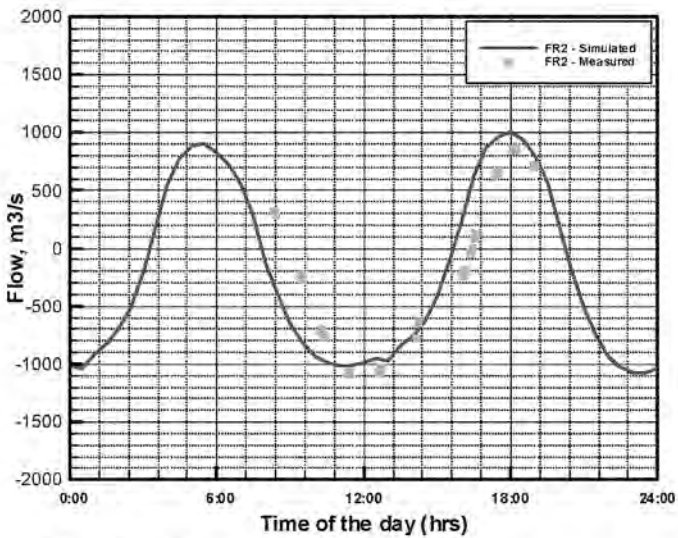


Figure G-8 Flow (m<sup>3</sup>/s) at Transect FR2 on September 30, 1997

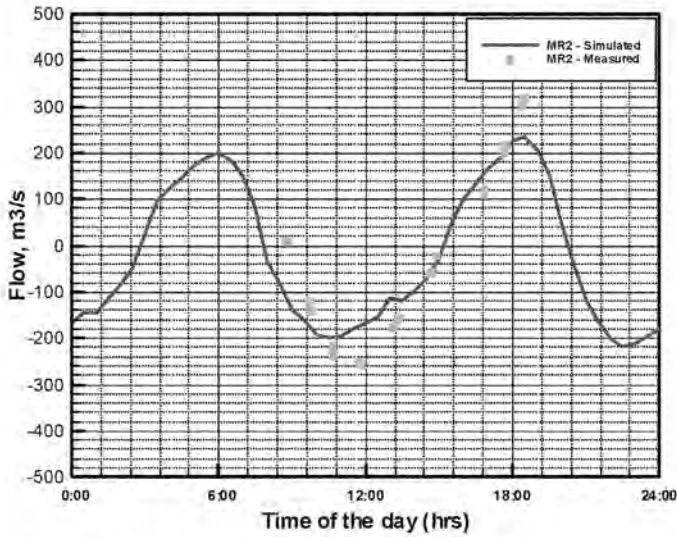


Figure G-9 Flow (m<sup>3</sup>/s) at Transect MR2 on September 30, 1997

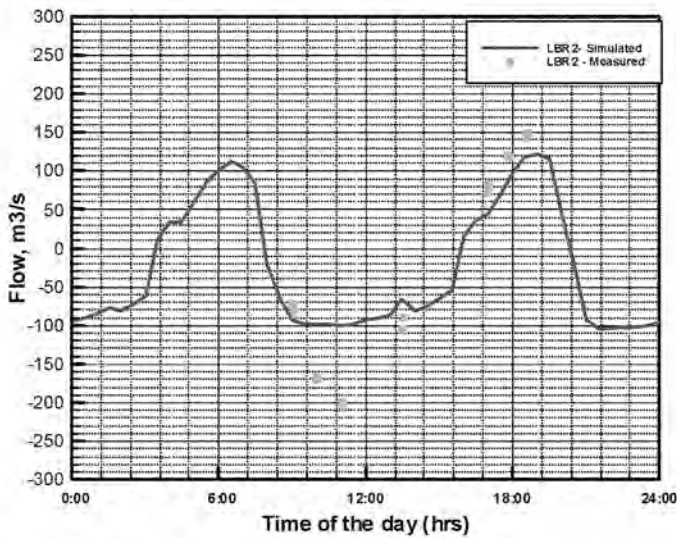


Figure G-10 Flow (m<sup>3</sup>/s) at Transect LBR2 on September 30, 1997

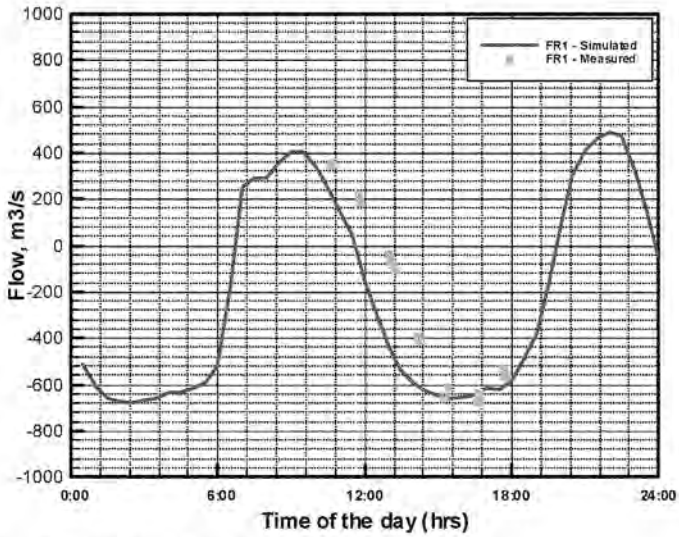


Figure G-11 Flow (m<sup>3</sup>/s) at Transect FR1 on October 6, 1997

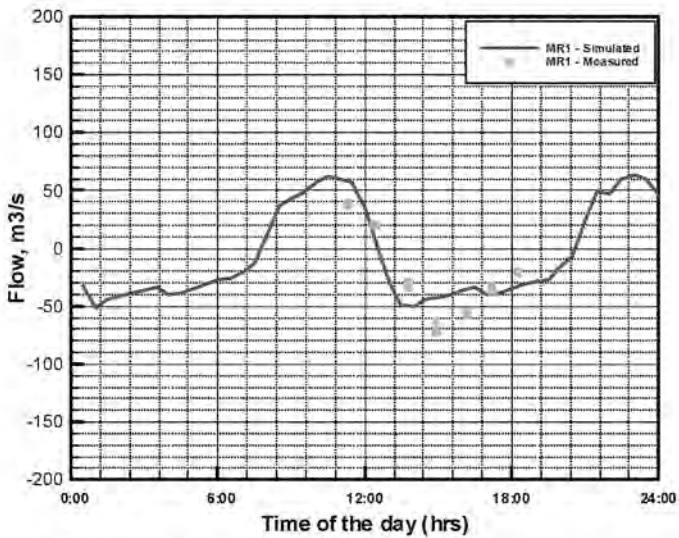
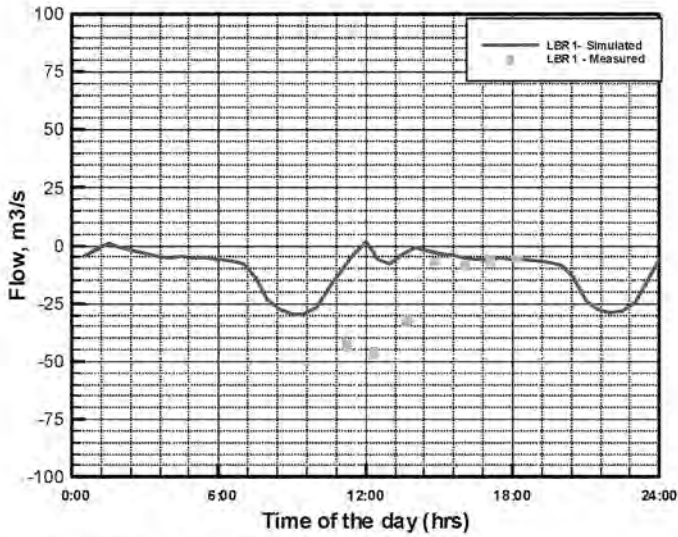
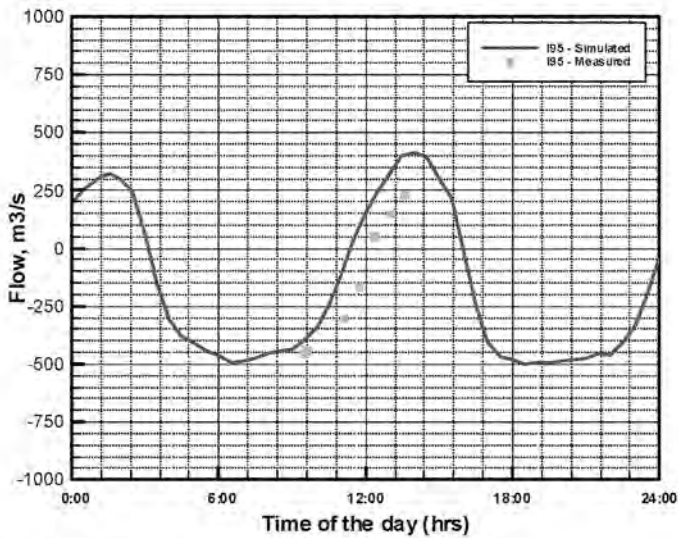


Figure G-12 Flow (m<sup>3</sup>/s) at Transect MR1 on October 6, 1997

Figure G-13 Flow (m<sup>3</sup>/s) at Transect LBR1 on October 6, 1997Figure G-14 Flow (m<sup>3</sup>/s) at Transect I95 on September 11, 1997

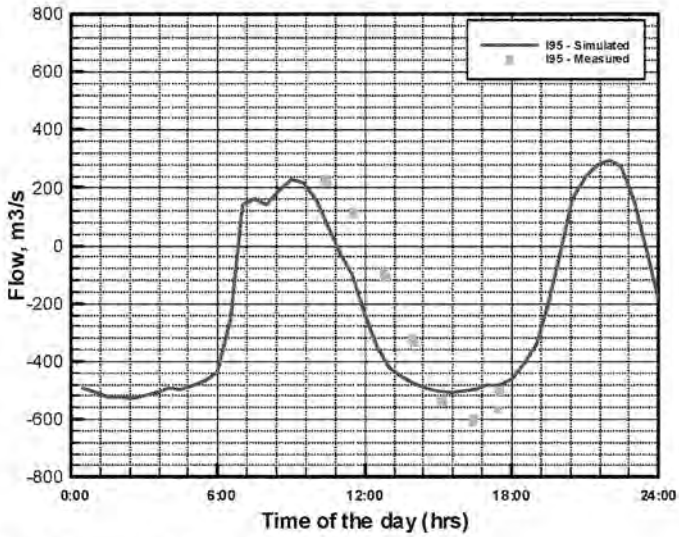


Figure G-15 Flow (m<sup>3</sup>/s) at Transect I95 on October 6, 1997

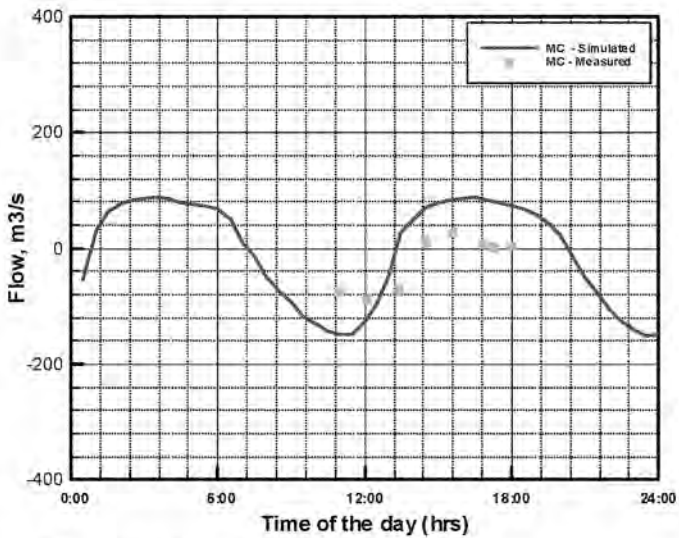


Figure G-16 Flow (m<sup>3</sup>/s) at Transect MC on October 6, 1997



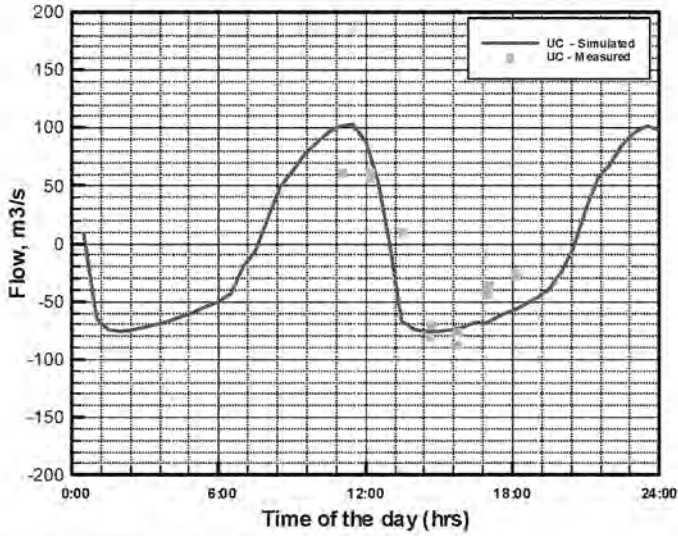


Figure G-17 Flow (m<sup>3</sup>/s) at Transect UC on October 6, 1997



**APPENDIX H 1999 TEMPERATURE COMPARISONS**



Table H-1 1999 Temperature Comparison Percentiles

| July 31 - October 13, 1999<br>[Julian Days 212-285] |        |              |               |            |                     |
|-----------------------------------------------------|--------|--------------|---------------|------------|---------------------|
| Stations                                            | Depth* | Measured 50% | Simulated 50% | Difference | Absolute Mean Error |
|                                                     |        | (deg C)      | (deg C)       | (deg C)    | (deg C)             |
| FR-26                                               | S      | 27.4         | 28            | 0.6        | 0.5                 |
| FR-26                                               | B      | 27.9         | 28.5          | 0.6        | 0.7                 |
| FR-02                                               | S      | 25.8         | 26.3          | 0.5        | 0.5                 |
| FR-02                                               | B      | 28.8         | 30.1          | 1.3        | 1.4                 |
| FR-04                                               | S      | 28.2         | 28.4          | 0.2        | 0.5                 |
| FR-04                                               | B      | 29.1         | 30.3          | 1.2        | 0.6                 |
| FR-21                                               | S      | 26.8         | 27.6          | 0.8        | 0.5                 |
| FR-21                                               | B      | 27.2         | 28.3          | 1.1        | 0.9                 |
| BR-05                                               | B      | 26.7         | 26.7          | 0.0        | 0.5                 |
| FR-06                                               | S      | 26.4         | 27.1          | 0.7        | 0.5                 |
| FR-06                                               | B      | 27.0         | 27.4          | 0.4        | 0.5                 |
| FR-22                                               | S      | 26.3         | 26.9          | 0.6        | 0.5                 |
| FR-22                                               | B      | 27.4         | 27.3          | -0.1       | 0.5                 |
| FR-08                                               | S      | 26.5         | 27.4          | 0.9        | 0.6                 |
| FR-08                                               | B      | 30.3         | 29.9          | -0.4       | 0.6                 |
| FR-09                                               | S      | 26.3         | 27            | 0.7        | 0.6                 |
| FR-09                                               | B      | 26.4         | 26.7          | 0.3        | 0.6                 |
| MR-10                                               | S      | 26.1         | 26.4          | 0.3        | 0.5                 |
| FR-11R                                              | B      | 25.7         | 26            | 0.3        | 0.6                 |
| SR-14                                               | B      | 25.6         | 26.1          | 0.5        | 0.5                 |

Table H-2 1999 Temperature Comparison Statistics

| July 31 - October 13, 1999<br>[Julian Days 212-285] |        |       |      |     |     |              |               |             |              |     |
|-----------------------------------------------------|--------|-------|------|-----|-----|--------------|---------------|-------------|--------------|-----|
| Station                                             | Depth* | N     | ME   | AME | RMS | Mean<br>Pred | StDev<br>Pred | Mean<br>Obs | StDev<br>Obs | R^2 |
| FR-26                                               | S      | 13600 | -0.1 | 0.5 | 0.6 | 27.4         | 2.6           | 27.5        | 2.8          | 1.0 |
| FR-26                                               | B      | 16940 | -0.6 | 0.7 | 1.0 | 27.4         | 2.5           | 28.0        | 2.8          | 0.9 |
| FR-02                                               | S      | 10346 | -0.3 | 0.5 | 0.7 | 26.4         | 2.4           | 26.8        | 2.6          | 1.0 |
| FR-02                                               | B      | 2225  | -1.4 | 1.4 | 1.4 | 28.8         | 0.3           | 30.2        | 0.3          | 0.3 |
| FR-04                                               | S      | 14937 | -0.2 | 0.5 | 0.6 | 28.1         | 2.6           | 28.2        | 2.7          | 1.0 |
| FR-04                                               | B      | 12963 | -0.5 | 0.6 | 0.8 | 28.3         | 2.8           | 28.7        | 3.0          | 1.0 |
| FR-21                                               | S      | 18694 | -0.3 | 0.5 | 0.6 | 27.2         | 2.8           | 27.5        | 2.8          | 1.0 |
| FR-21                                               | B      | 16674 | -0.8 | 0.9 | 1.2 | 27.5         | 2.8           | 28.3        | 2.7          | 0.9 |
| BR-05                                               | B      | 11806 | 0.3  | 0.5 | 0.6 | 26.8         | 2.1           | 26.4        | 2.3          | 0.9 |
| FR-06                                               | S      | 11862 | -0.1 | 0.5 | 0.6 | 26.5         | 2.4           | 26.6        | 2.7          | 1.0 |
| FR-06                                               | B      | 15018 | 0.0  | 0.5 | 0.6 | 26.8         | 2.1           | 26.7        | 2.5          | 1.0 |
| FR-22                                               | S      | 18949 | -0.1 | 0.5 | 0.6 | 26.9         | 2.7           | 27.1        | 2.7          | 1.0 |
| FR-22                                               | B      | 18570 | 0.3  | 0.5 | 0.6 | 27.6         | 2.6           | 27.3        | 2.8          | 1.0 |
| FR-08                                               | S      | 11922 | 0.1  | 0.6 | 0.8 | 27.4         | 3.3           | 27.3        | 3.6          | 1.0 |
| FR-08                                               | B      | 8385  | -0.2 | 0.6 | 0.7 | 28.6         | 2.6           | 28.7        | 2.4          | 0.9 |
| FR-09                                               | S      | 18337 | -0.1 | 0.6 | 0.8 | 27.0         | 2.7           | 27.1        | 2.9          | 0.9 |
| FR-09                                               | B      | 18471 | 0.2  | 0.6 | 0.8 | 27.1         | 2.7           | 26.9        | 3.0          | 0.9 |
| MR-10                                               | S      | 15570 | 0.1  | 0.5 | 0.6 | 26.6         | 2.6           | 26.5        | 2.7          | 1.0 |
| FR-11R                                              | B      | 16657 | 0.1  | 0.6 | 0.7 | 26.2         | 2.4           | 26.1        | 2.4          | 0.9 |
| SR-14                                               | M      | 12348 | 0.0  | 0.5 | 0.7 | 25.9         | 2.3           | 25.9        | 2.3          | 0.9 |

\* S = Surface

B = Bottom

M = Mid-Depth

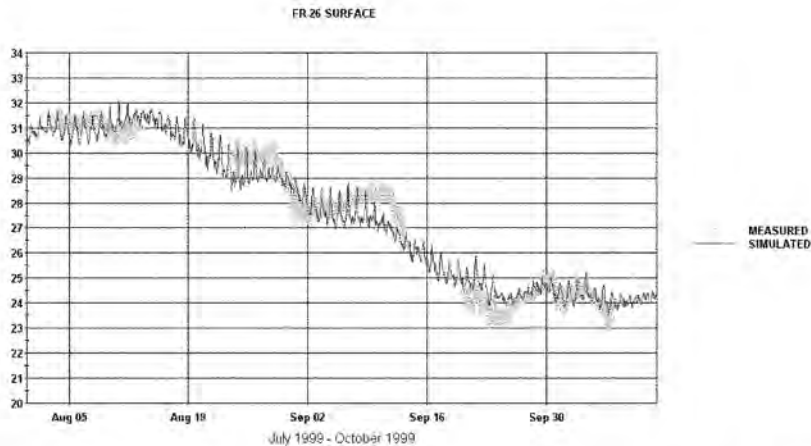


Figure H-1 Temperature (degrees C) Comparisons at FR-26 (Surface) for July 31, 1999 through October 13, 1999

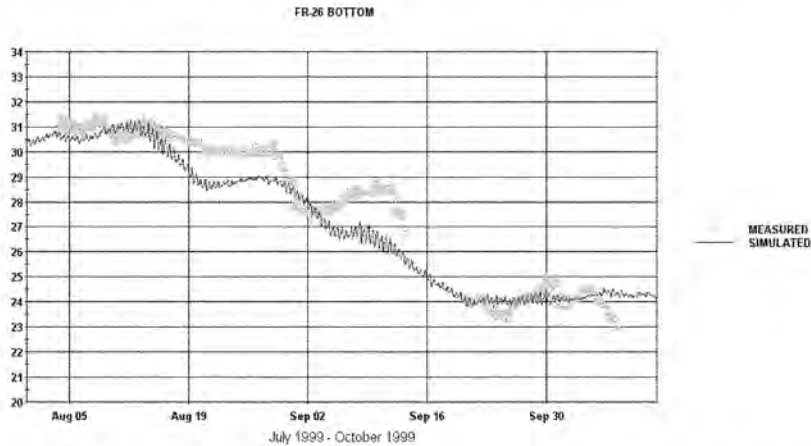


Figure H-2 Temperature (degrees C) Comparisons at FR-26 (Bottom) for July 31, 1999 through October 13, 1999

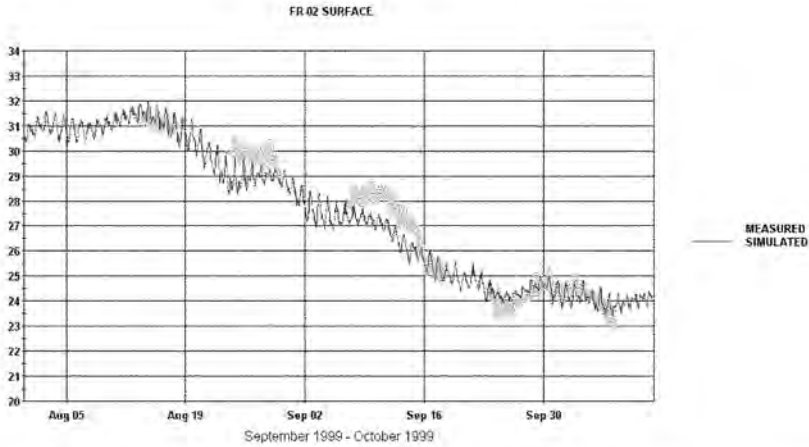


Figure H-3 Temperature (degrees C) Comparisons at FR-02 (Surface) for July 31, 1999 through October 13, 1999

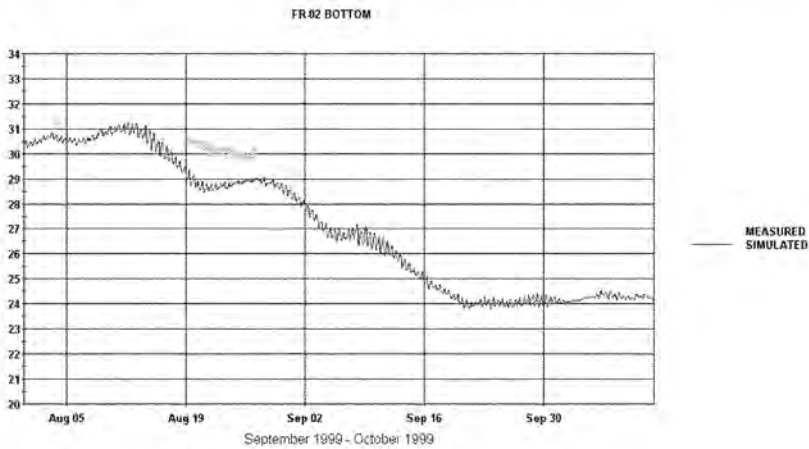


Figure H-4 Temperature (degrees C) Comparisons at FR-02 (Bottom) for July 31, 1999 through October 13, 1999



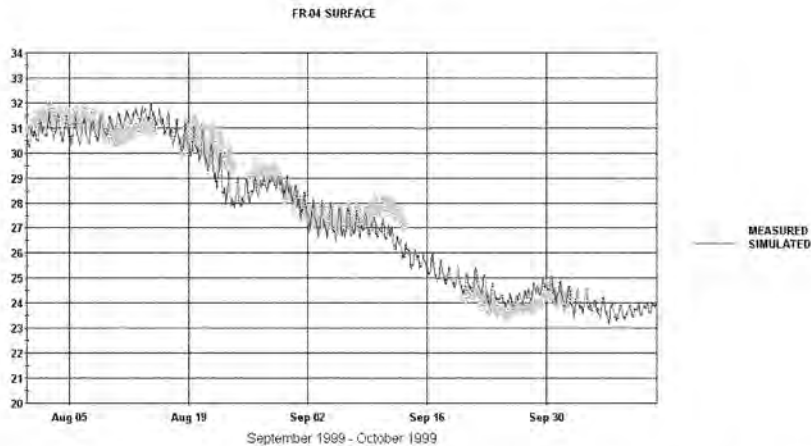


Figure H-5 Temperature (degrees C) Comparisons at FR-04 (Surface) for July 31, 1999 through October 13, 1999

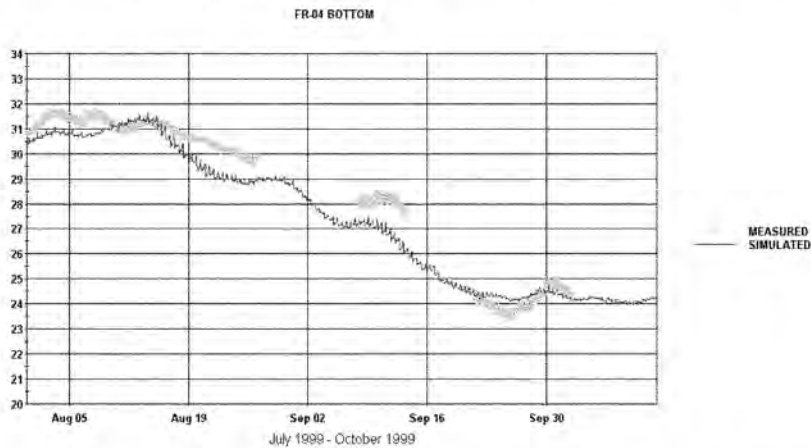


Figure H-6 Temperature (degrees C) Comparisons at FR-04 (Bottom) for July 31, 1999 through October 13, 1999

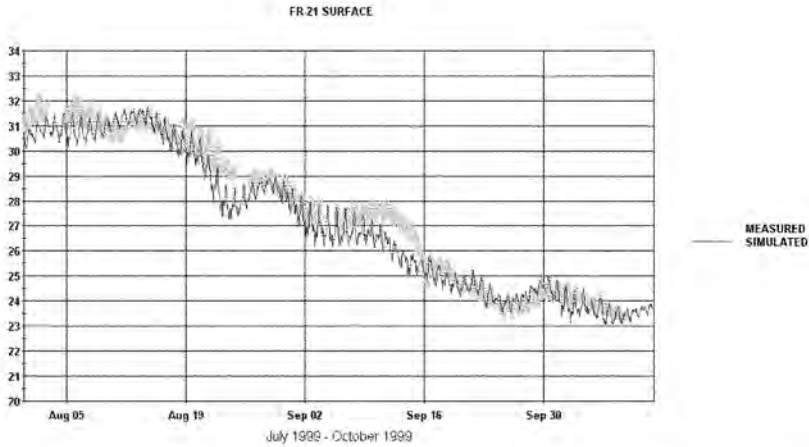


Figure H-7 Temperature (degrees C) Comparisons at FR-21 (Surface) for July 31, 1999 through October 13, 1999

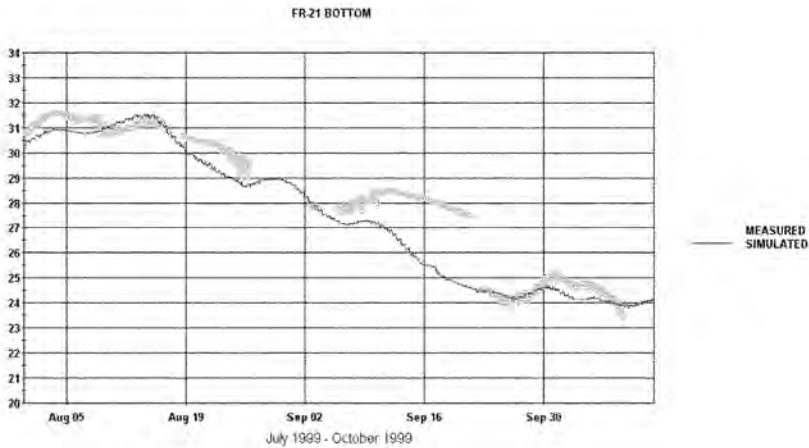


Figure H-8 Temperature (degrees C) Comparisons at FR-21 (Bottom) for July 31, 1999 through October 13, 1999

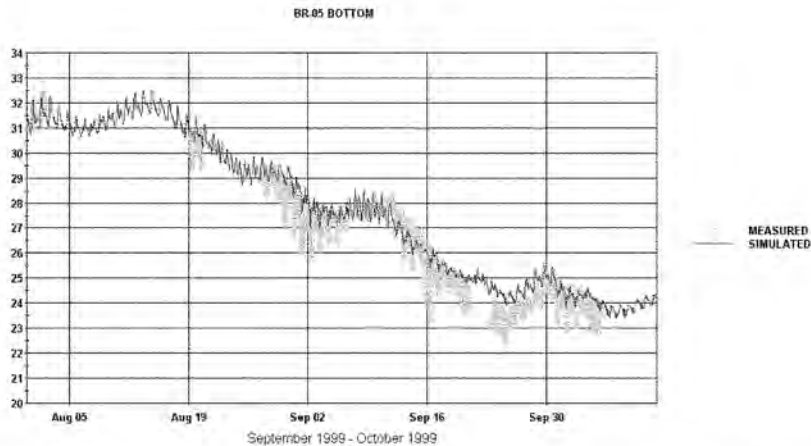


Figure H-9      Temperature (degrees C) Comparisons at BR-05 (Bottom) for July 31, 1999 through October 13, 1999

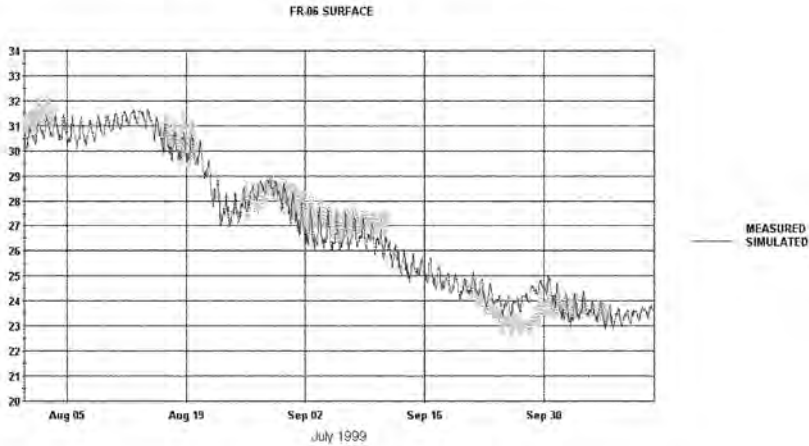


Figure H-10      Temperature (degrees C) Comparisons at FR-06 (Surface) for July 31, 1999 through October 13, 1999

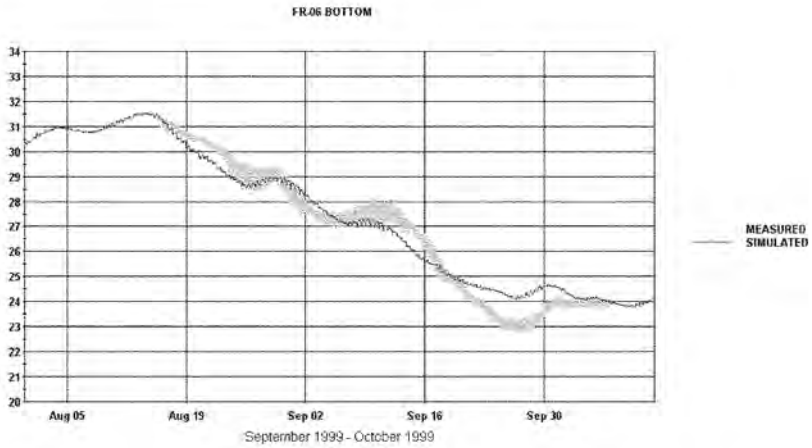


Figure H-11 Temperature (degrees C) Comparisons at FR-06 (Bottom) for July 31, 1999 through October 13, 1999

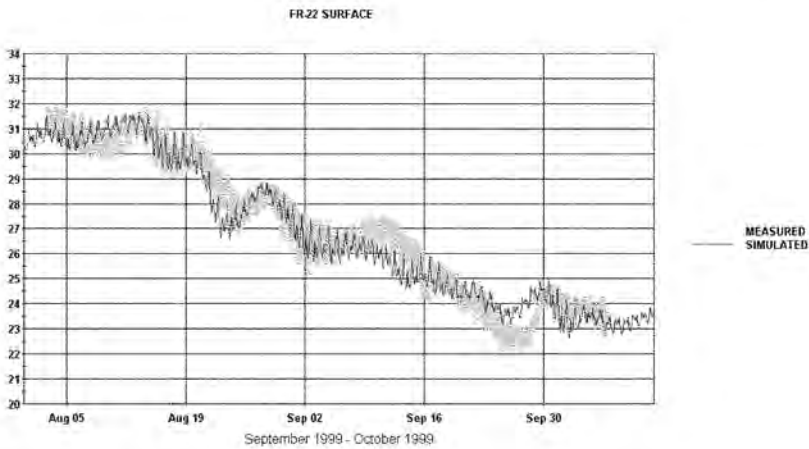


Figure H-12 Temperature (degrees C) Comparisons at FR-22 (Surface) for July 31, 1999 through October 13, 1999

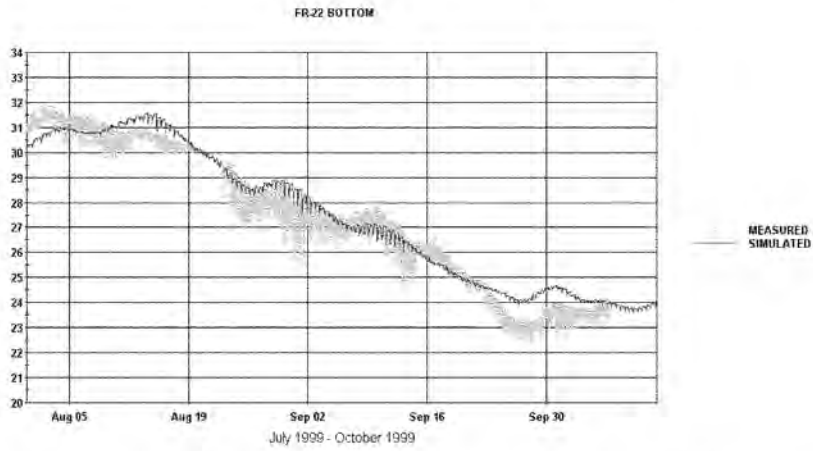


Figure H-13 Temperature (degrees C) Comparisons at FR-22 (Bottom) for July 31, 1999 through October 13, 1999

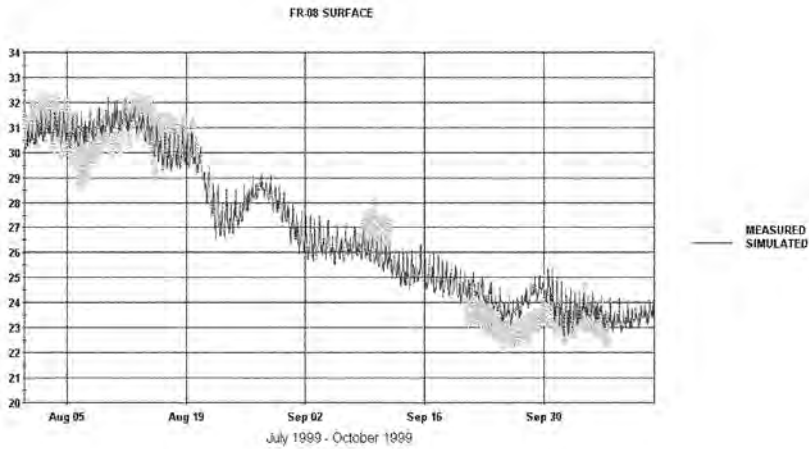


Figure H-14 Temperature (degrees C) Comparisons at FR-08 (Surface) for July 31, 1999 through October 13, 1999

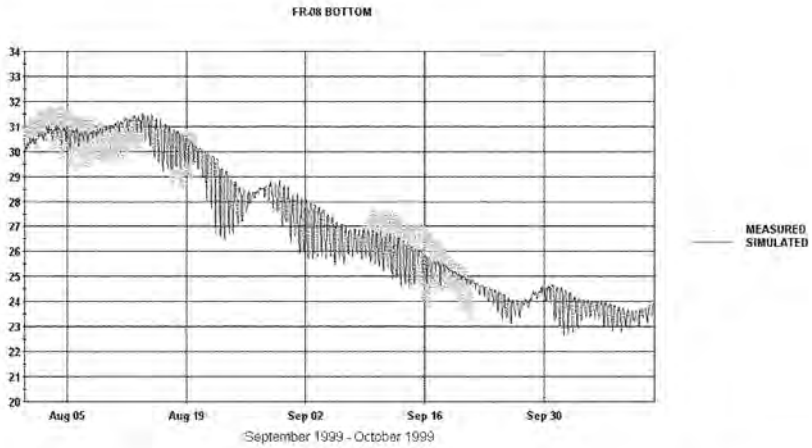


Figure H-15 Temperature (degrees C) Comparisons at FR-08 (Bottom) for July 31, 1999 through October 13, 1999

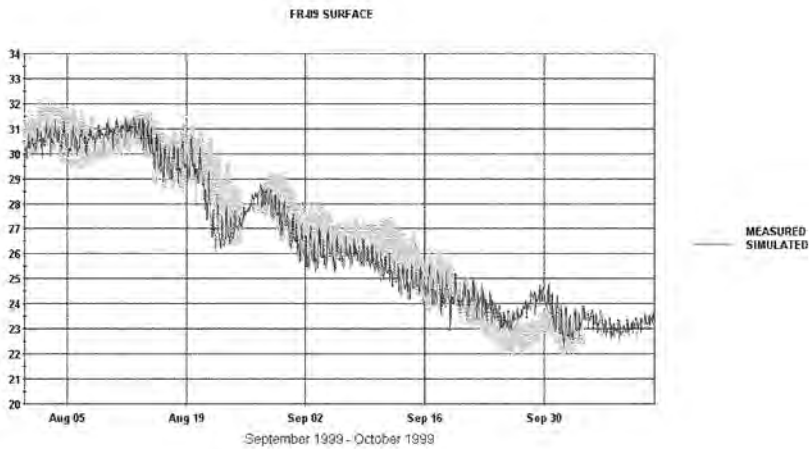


Figure H-16 Temperature (degrees C) Comparisons at FR-09 (Surface) for July 31, 1999 through October 13, 1999

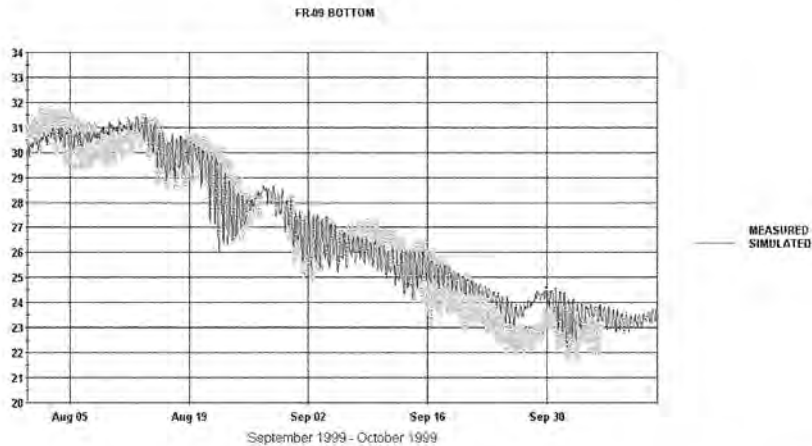


Figure H-17 Temperature (degrees C) Comparisons at FR-09 (Bottom) for July 31, 1999 through October 13, 1999

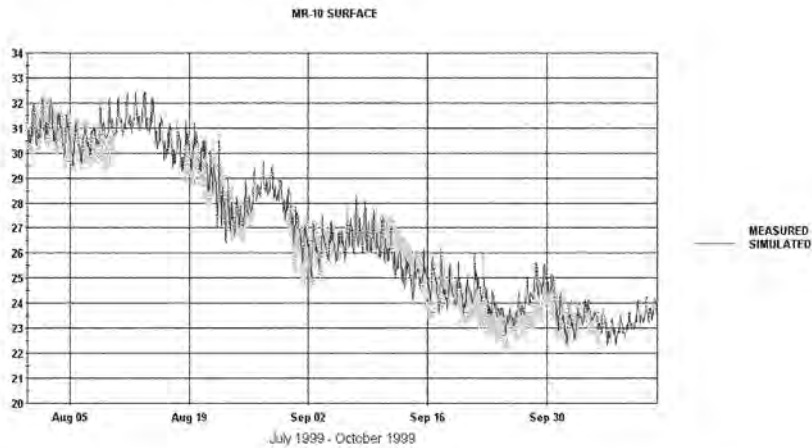


Figure H-18 Temperature (degrees C) Comparisons at MR-10 (Surface) for July 31, 1999 through October 13, 1999

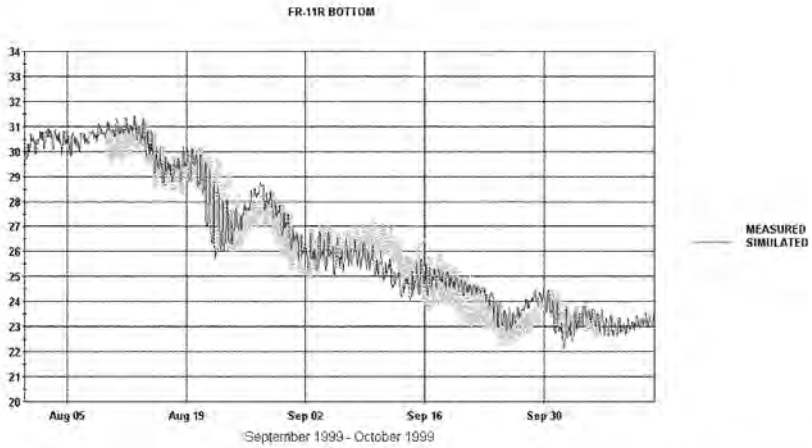


Figure H-19 Temperature (degrees C) Comparisons at FR-11R (Bottom) for July 31, 1999 through October 13, 1999

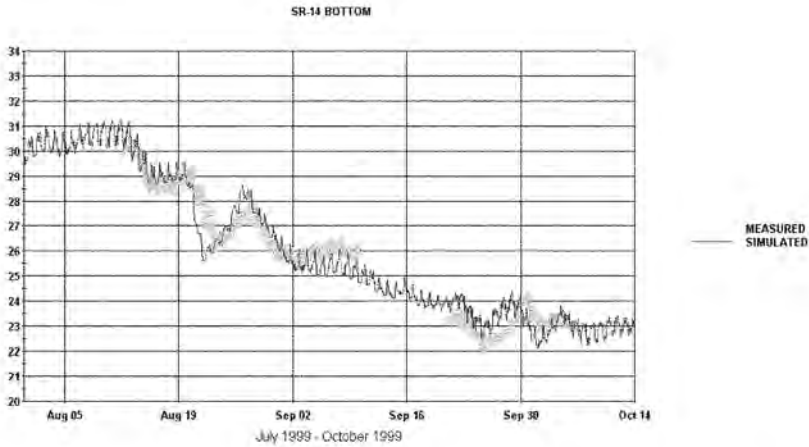


Figure H-20 Temperature (degrees C) Comparisons at SR-14 (Bottom) for July 31, 1999 through October 13, 1999



Table H-3 Temperature Comparison Percentiles, August 1 through August 15, 1999

| August 1 - August 15, 1999<br>(Julian Days 213-226) |        |              |               |            |                     |
|-----------------------------------------------------|--------|--------------|---------------|------------|---------------------|
| Stations                                            | Depth* | Measured 50% | Simulated 50% | Difference | Absolute Mean Error |
|                                                     |        | (deg C)      | (deg C)       | (deg C)    | (deg C)             |
| FR-26                                               | S      | 31.2         | 31.1          | -0.1       | 0.39                |
| FR-26                                               | B      | 31.0         | 30.5          | -0.5       | 0.51                |
| FR-02                                               | S      | 31.3         | 31.2          | -0.1       | 0.39                |
| FR-02                                               | B      | 31.2         | 30.7          | -0.5       | 0.46                |
| FR-04                                               | S      | 31.3         | 31.2          | -0.1       | 0.46                |
| FR-04                                               | B      | 31.4         | 30.9          | -0.5       | 0.47                |
| FR-21                                               | S      | 31.3         | 31.0          | -0.2       | 0.41                |
| FR-21                                               | B      | 31.4         | 30.8          | -0.6       | 0.47                |
| BR-05                                               | B      | 31.2         | 31.5          | 0.3        | 0.59                |
| FR-06                                               | S      | 31.6         | 30.8          | -0.7       | 0.66                |
| FR-06                                               | B      | 0.0          | 0.0           | 0.0        | 0.00                |
| FR-22                                               | S      | 30.8         | 30.9          | 0.1        | 0.49                |
| FR-22                                               | B      | 31.1         | 30.9          | -0.2       | 0.51                |
| FR-08                                               | S      | 30.6         | 30.9          | 0.4        | 0.71                |
| FR-08                                               | B      | 30.9         | 30.9          | -0.1       | 0.48                |
| FR-09                                               | S      | 30.7         | 30.8          | 0.1        | 0.50                |
| FR-09                                               | B      | 30.7         | 30.8          | 0.1        | 0.50                |
| MR-10                                               | S      | 30.6         | 31.0          | 0.4        | 0.61                |
| FR-11R                                              | B      | 30.2         | 30.9          | 0.6        | 0.51                |
| SR-14                                               | B      | 29.6         | 29.9          | 0.3        | 0.39                |

\* S = Surface

B = Bottom

Table H-4 Temperature Comparison Statistics, August 1 through August 15, 1999

| August 1 - August 15, 1999<br>(Julian Days 213-226) |       |      |       |      |      |          |           |           |            |                |
|-----------------------------------------------------|-------|------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Station                                             | Depth | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-26                                               | S     | 2874 | -0.05 | 0.39 | 0.46 | 31.14    | 0.29      | 31.09     | 0.36       | 0.00           |
| FR-26                                               | B     | 3601 | -0.47 | 0.51 | 0.59 | 30.97    | 0.24      | 30.50     | 0.30       | 0.04           |
| FR-02                                               | S     | 3564 | -0.11 | 0.39 | 0.44 | 31.26    | 0.26      | 31.15     | 0.37       | 0.01           |
| FR-02                                               | B     | 3590 | -0.42 | 0.46 | 0.54 | 31.15    | 0.22      | 30.73     | 0.25       | 0.00           |
| FR-04                                               | S     | 4299 | -0.17 | 0.46 | 0.51 | 31.30    | 0.30      | 31.14     | 0.37       | 0.00           |
| FR-04                                               | B     | 4321 | -0.39 | 0.47 | 0.56 | 31.36    | 0.20      | 30.97     | 0.27       | 0.26           |
| FR-21                                               | S     | 3251 | -0.31 | 0.41 | 0.52 | 31.34    | 0.32      | 31.04     | 0.37       | 0.07           |
| FR-21                                               | B     | 3076 | -0.37 | 0.47 | 0.55 | 31.40    | 0.16      | 31.03     | 0.32       | 0.20           |
| BR-05                                               | B     | 4303 | 0.33  | 0.59 | 0.72 | 31.14    | 0.55      | 31.47     | 0.46       | 0.06           |
| FR-06                                               | S     | 747  | -0.66 | 0.66 | 0.67 | 31.54    | 0.27      | 30.88     | 0.28       | 0.82           |
| FR-06                                               | B     | 0    | 0.00  | 0.00 | 0.00 | 0.00     | 0.00      | 0.00      | 0.00       | 0.00           |
| FR-22                                               | S     | 3848 | 0.24  | 0.49 | 0.58 | 30.82    | 0.47      | 31.07     | 0.27       | 0.00           |
| FR-22                                               | B     | 4321 | -0.09 | 0.51 | 0.55 | 31.11    | 0.37      | 31.02     | 0.28       | 0.17           |
| FR-08                                               | S     | 4321 | 0.41  | 0.71 | 0.85 | 30.54    | 0.78      | 30.96     | 0.39       | 0.13           |
| FR-08                                               | B     | 4308 | 0.08  | 0.48 | 0.55 | 30.80    | 0.80      | 30.88     | 0.32       | 0.16           |
| FR-09                                               | S     | 4321 | 0.10  | 0.50 | 0.59 | 30.67    | 0.64      | 30.77     | 0.38       | 0.20           |
| FR-09                                               | B     | 4321 | 0.13  | 0.50 | 0.58 | 30.67    | 0.63      | 30.79     | 0.35       | 0.21           |
| MR-10                                               | S     | 4312 | 0.46  | 0.61 | 0.74 | 30.56    | 0.65      | 31.02     | 0.57       | 0.30           |
| FR-11R                                              | B     | 1829 | 0.49  | 0.51 | 0.59 | 30.21    | 0.55      | 30.70     | 0.55       | 0.67           |
| SR-14                                               | B     | 508  | 0.33  | 0.39 | 0.49 | 29.63    | 0.66      | 29.95     | 0.76       | 0.77           |

\* S = Surface

B = Bottom

Table H-5 Temperature Comparison Percentiles, August 15 through August 30, 1999

| August 15 - August 30, 1999<br>(Julian Days 227-241) |                    |              |               |            |                     |
|------------------------------------------------------|--------------------|--------------|---------------|------------|---------------------|
| Stations                                             | Depth <sup>a</sup> | Measured 50% | Simulated 50% | Difference | Absolute Mean Error |
|                                                      |                    | (deg C)      | (deg C)       | (deg C)    | (deg C)             |
| FR-26                                                | S                  | 29.9         | 29.0          | -0.8       | 0.63                |
| FR-26                                                | B                  | 30.1         | 28.7          | -1.4       | 1.31                |
| FR-02                                                | S                  | 30.2         | 29.4          | -0.8       | 0.50                |
| FR-02                                                | B                  | 30.3         | 28.9          | -1.4       | 1.18                |
| FR-04                                                | S                  | 30.2         | 29.5          | -0.6       | 0.46                |
| FR-04                                                | B                  | 30.2         | 29.1          | -1.1       | 0.83                |
| FR-21                                                | S                  | 29.9         | 28.9          | -1.0       | 0.59                |
| FR-21                                                | B                  | 30.5         | 29.6          | -0.9       | 0.77                |
| BR-05                                                | B                  | 30.1         | 30.9          | 0.8        | 0.75                |
| FR-06                                                | S                  | 29.2         | 28.6          | -0.6       | 0.60                |
| FR-06                                                | B                  | 30.1         | 29.1          | -1.0       | 0.55                |
| FR-22                                                | S                  | 28.6         | 29.4          | 0.6        | 0.71                |
| FR-22                                                | B                  | 29.2         | 28.9          | -0.3       | 0.34                |
| FR-08                                                | S                  | 28.8         | 29.6          | 0.7        | 0.60                |
| FR-08                                                | B                  | 29.2         | 28.9          | -0.3       | 0.45                |
| FR-09                                                | S                  | 28.8         | 28.5          | -0.3       | 0.56                |
| FR-09                                                | B                  | 29.1         | 29.2          | 0.1        | 0.39                |
| MR-10                                                | S                  | 28.9         | 29.3          | 0.4        | 0.62                |
| FR-11R                                               | B                  | 28.2         | 28.3          | 0.1        | 0.49                |
| SR-14                                                | B                  | 27.4         | 27.5          | 0.2        | 0.57                |

\* S = Surface

B = Bottom

Table H-6 Temperature Comparison Statistics, August 15 through August 30, 1999

| August 15 - August 30, 1999<br>(Julian Days 227-241) |       |      |       |      |      |          |           |           |            |                |
|------------------------------------------------------|-------|------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Station                                              | Depth | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-26                                                | S     | 955  | -0.59 | 0.63 | 0.73 | 29.73    | 0.44      | 29.14     | 0.34       | 0.20           |
| FR-26                                                | B     | 4806 | -1.31 | 1.31 | 1.35 | 30.15    | 0.43      | 28.84     | 0.48       | 0.56           |
| FR-02                                                | S     | 1788 | -0.35 | 0.50 | 0.65 | 30.36    | 0.76      | 30.01     | 1.16       | 0.85           |
| FR-02                                                | B     | 3420 | -1.18 | 1.18 | 1.22 | 30.37    | 0.37      | 29.19     | 0.60       | 0.75           |
| FR-04                                                | S     | 3985 | -0.38 | 0.46 | 0.62 | 30.06    | 0.80      | 29.68     | 1.04       | 0.80           |
| FR-04                                                | B     | 4393 | -0.82 | 0.83 | 0.89 | 30.25    | 0.55      | 29.42     | 0.70       | 0.77           |
| FR-21                                                | S     | 4119 | -0.58 | 0.59 | 0.77 | 29.92    | 0.87      | 29.34     | 1.08       | 0.79           |
| FR-21                                                | B     | 2703 | -0.74 | 0.77 | 0.84 | 30.45    | 0.52      | 29.70     | 0.82       | 0.87           |
| BR-05                                                | B     | 2587 | 0.69  | 0.75 | 0.89 | 29.86    | 0.96      | 30.55     | 1.15       | 0.77           |
| FR-06                                                | S     | 4206 | -0.59 | 0.60 | 0.79 | 29.43    | 0.85      | 28.84     | 1.02       | 0.73           |
| FR-06                                                | B     | 4208 | -0.55 | 0.55 | 0.63 | 30.00    | 0.73      | 29.46     | 0.75       | 0.83           |
| FR-22                                                | S     | 4542 | 0.68  | 0.71 | 0.82 | 28.93    | 1.06      | 29.60     | 0.96       | 0.81           |
| FR-22                                                | B     | 3478 | 0.02  | 0.34 | 0.42 | 29.53    | 0.99      | 29.55     | 1.09       | 0.85           |
| FR-08                                                | S     | 2617 | 0.57  | 0.60 | 0.72 | 28.72    | 0.89      | 29.29     | 0.99       | 0.80           |
| FR-08                                                | B     | 4609 | -0.10 | 0.45 | 0.58 | 29.19    | 1.25      | 29.09     | 1.14       | 0.79           |
| FR-09                                                | S     | 4064 | -0.24 | 0.56 | 0.75 | 28.75    | 1.20      | 28.51     | 1.22       | 0.68           |
| FR-09                                                | B     | 3646 | -0.12 | 0.39 | 0.52 | 29.00    | 1.19      | 28.88     | 1.24       | 0.53           |
| MR-10                                                | S     | 3070 | 0.31  | 0.62 | 0.77 | 28.78    | 1.08      | 29.10     | 1.32       | 0.71           |
| FR-11R                                               | B     | 4548 | 0.09  | 0.49 | 0.63 | 28.21    | 1.11      | 28.30     | 1.14       | 0.72           |
| SR-14                                                | B     | 3960 | 0.07  | 0.57 | 0.71 | 27.54    | 0.96      | 27.61     | 1.08       | 0.59           |

\* S = Surface

B = Bottom

Table H-7 Temperature Comparison Percentiles, August 30 through September 13, 1999

| August 30 - September 13, 1999<br>(Julian Days 242-255) |        |              |               |            |                     |
|---------------------------------------------------------|--------|--------------|---------------|------------|---------------------|
| Stations                                                | Depth* | Measured 50% | Simulated 50% | Difference | Absolute Mean Error |
|                                                         |        | (deg C)      | (deg C)       | (deg C)    | (deg C)             |
| FR-26                                                   | S      | 28.1         | 27.4          | -0.7       | 0.70                |
| FR-26                                                   | B      | 28.1         | 26.6          | -1.5       | 1.39                |
| FR-02                                                   | S      | 28.1         | 27.3          | -0.8       | 0.77                |
| FR-02                                                   | B      |              |               |            |                     |
| FR-04                                                   | S      | 27.8         | 27.1          | -0.6       | 0.54                |
| FR-04                                                   | B      | 26.1         | 27.3          | 0.8        | 0.72                |
| FR-21                                                   | S      | 27.7         | 26.8          | -0.9       | 0.76                |
| FR-21                                                   | B      | 28.1         | 27.2          | -0.9       | 0.90                |
| BR-05                                                   | B      | 27.6         | 27.7          | 0.1        | 0.47                |
| FR-06                                                   | S      | 27.4         | 26.7          | -0.8       | 0.61                |
| FR-06                                                   | B      | 27.8         | 27.3          | -0.5       | 0.47                |
| FR-22                                                   | S      | 26.9         | 27.1          | 0.3        | 0.66                |
| FR-22                                                   | B      | 27.4         | 27.1          | -0.2       | 0.36                |
| FR-08                                                   | S      | 26.7         | 26.3          | -0.4       | 0.47                |
| FR-08                                                   | B      | 26.9         | 26.6          | -0.3       | 0.50                |
| FR-09                                                   | S      | 26.5         | 25.9          | -0.6       | 0.64                |
| FR-09                                                   | B      | 26.7         | 26.1          | -0.6       | 0.58                |
| MR-10                                                   | S      | 26.6         | 26.4          | -0.1       | 0.46                |
| FR-11R                                                  | B      | 26.2         | 25.8          | -0.4       | 0.52                |
| SR-14                                                   | B      | 26.0         | 25.6          | -0.4       | 0.46                |

\* S = Surface

B = Bottom

Table H-8 Temperature Comparison Statistics, August 30 through September 13, 1999

| August 30 - September 13, 1999<br>(Julian Days 242-255) |       |      |       |      |      |          |           |           |            |                |
|---------------------------------------------------------|-------|------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Station                                                 | Depth | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-26                                                   | S     | 2650 | -0.54 | 0.70 | 0.82 | 28.04    | 0.47      | 27.51     | 0.69       | 0.23           |
| FR-26                                                   | B     | 3802 | -1.37 | 1.39 | 1.68 | 28.13    | 0.47      | 26.76     | 0.93       | 0.02           |
| FR-02                                                   | S     | 2976 | -0.74 | 0.77 | 0.88 | 28.07    | 0.42      | 27.34     | 0.67       | 0.49           |
| FR-02                                                   | B     | 0    |       |      |      |          |           |           |            |                |
| FR-04                                                   | S     | 4155 | -0.52 | 0.54 | 0.65 | 27.82    | 0.41      | 27.30     | 0.67       | 0.68           |
| FR-04                                                   | B     | 4155 | -0.67 | 0.72 | 0.80 | 28.16    | 0.41      | 27.49     | 0.72       | 0.30           |
| FR-21                                                   | S     | 3816 | -0.76 | 0.76 | 0.88 | 27.72    | 0.44      | 26.95     | 0.75       | 0.75           |
| FR-21                                                   | B     | 2811 | -0.86 | 0.90 | 1.04 | 28.02    | 0.23      | 27.16     | 0.43       | 0.31           |
| BR-05                                                   | B     | 4320 | 0.19  | 0.47 | 0.59 | 27.58    | 0.55      | 27.77     | 0.63       | 0.32           |
| FR-06                                                   | S     | 3656 | -0.61 | 0.61 | 0.69 | 27.48    | 0.46      | 26.85     | 0.54       | 0.75           |
| FR-06                                                   | B     | 4311 | -0.37 | 0.47 | 0.58 | 27.89    | 0.43      | 27.52     | 0.70       | 0.62           |
| FR-22                                                   | S     | 4290 | 0.54  | 0.66 | 0.87 | 26.85    | 0.54      | 27.40     | 0.70       | 0.19           |
| FR-22                                                   | B     | 4284 | 0.10  | 0.36 | 0.47 | 27.29    | 0.70      | 27.39     | 0.70       | 0.61           |
| FR-08                                                   | S     | 3651 | -0.26 | 0.47 | 0.57 | 26.72    | 0.61      | 26.46     | 0.60       | 0.41           |
| FR-08                                                   | B     | 4321 | -0.20 | 0.50 | 0.59 | 26.81    | 0.73      | 26.61     | 0.85       | 0.58           |
| FR-09                                                   | S     | 4115 | -0.52 | 0.64 | 0.76 | 26.56    | 0.65      | 26.05     | 0.71       | 0.44           |
| FR-09                                                   | B     | 4157 | -0.44 | 0.58 | 0.69 | 26.61    | 0.62      | 26.17     | 0.73       | 0.48           |
| MR-10                                                   | S     | 4074 | -0.05 | 0.46 | 0.59 | 26.49    | 0.62      | 26.45     | 0.73       | 0.40           |
| FR-11R                                                  | B     | 4036 | -0.36 | 0.52 | 0.62 | 26.23    | 0.53      | 25.87     | 0.70       | 0.49           |
| SR-14                                                   | B     | 3232 | -0.31 | 0.46 | 0.54 | 25.97    | 0.23      | 25.66     | 0.52       | 0.26           |

\* S = Surface

B = Bottom

Table H-9 Temperature Comparison Percentiles, September 13 through September 28, 1999

| September 13 - September 28, 1999<br>(Julian Days 256-270) |        |              |               |            |                     |
|------------------------------------------------------------|--------|--------------|---------------|------------|---------------------|
| Stations                                                   | Depth* | Measured 50% | Simulated 50% | Difference | Absolute Mean Error |
|                                                            |        | (deg C)      | (deg C)       | (deg C)    | (deg C)             |
| FR-26                                                      | S      | 24.1         | 24.5          | 0.4        | 0.57                |
| FR-26                                                      | B      | 24.0         | 23.8          | -0.2       | 0.38                |
| FR-02                                                      | S      | 24.4         | 24.8          | 0.4        | 0.44                |
| FR-02                                                      | B      |              |               |            |                     |
| FR-04                                                      | S      | 24.0         | 24.4          | 0.3        | 0.36                |
| FR-04                                                      | B      | 24.0         | 24.3          | 0.3        | 0.39                |
| FR-21                                                      | S      | 24.7         | 24.6          | -0.1       | 0.38                |
| FR-21                                                      | B      | 27.4         | 24.7          | -2.7       | 1.61                |
| BR-05                                                      | B      | 24.6         | 25.1          | 0.5        | 0.61                |
| FR-06                                                      | S      | 24.0         | 24.2          | 0.2        | 0.20                |
| FR-06                                                      | B      | 24.9         | 24.7          | -0.2       | 0.53                |
| FR-22                                                      | S      | 24.3         | 24.8          | 0.5        | 0.62                |
| FR-22                                                      | B      | 24.2         | 24.8          | 0.6        | 0.56                |
| FR-08                                                      | S      | 23.6         | 24.1          | 0.5        | 0.53                |
| FR-08                                                      | B      | 24.7         | 24.7          | 0.1        | 0.51                |
| FR-09                                                      | S      | 24.1         | 24.3          | 0.2        | 0.49                |
| FR-09                                                      | B      | 24.2         | 24.5          | 0.3        | 0.51                |
| MR-10                                                      | S      | 23.8         | 24.4          | 0.6        | 0.56                |
| FR-11R                                                     | B      | 23.9         | 24.5          | 0.6        | 0.57                |
| SR-14                                                      | B      | 22.7         | 23.7          | 0.9        | 0.84                |

\* S = Surface

B = Bottom

Table H-10 Temperature Comparison Statistics, September 13 through September 28, 1999

| September 13 - September 28, 1999<br>(Julian Days 256-270) |       |      |       |      |      |          |           |           |            |      |
|------------------------------------------------------------|-------|------|-------|------|------|----------|-----------|-----------|------------|------|
| Station                                                    | Depth | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R^2  |
| FR-26                                                      | S     | 2545 | 0.51  | 0.57 | 0.69 | 24.10    | 0.71      | 24.62     | 0.51       | 0.57 |
| FR-26                                                      | B     | 2583 | -0.17 | 0.39 | 0.55 | 24.08    | 0.79      | 23.91     | 0.39       | 0.66 |
| FR-02                                                      | S     | 3431 | -0.02 | 0.44 | 0.56 | 25.02    | 1.23      | 25.00     | 0.77       | 0.89 |
| FR-02                                                      | B     | 0    |       |      |      |          |           |           |            |      |
| FR-04                                                      | S     | 2595 | 0.23  | 0.36 | 0.44 | 24.26    | 0.74      | 24.50     | 0.47       | 0.82 |
| FR-04                                                      | B     | 2595 | 0.24  | 0.39 | 0.51 | 24.19    | 0.85      | 24.42     | 0.42       | 0.85 |
| FR-21                                                      | S     | 4601 | -0.22 | 0.38 | 0.56 | 24.93    | 1.02      | 24.71     | 0.61       | 0.86 |
| FR-21                                                      | B     | 4094 | -1.34 | 1.61 | 1.93 | 26.28    | 1.88      | 24.93     | 0.66       | 0.67 |
| BR-05                                                      | B     | 3892 | 0.49  | 0.61 | 0.77 | 24.75    | 1.20      | 25.24     | 0.84       | 0.79 |
| FR-06                                                      | S     | 2424 | 0.17  | 0.20 | 0.24 | 24.04    | 0.37      | 24.21     | 0.37       | 0.79 |
| FR-06                                                      | B     | 4609 | -0.25 | 0.53 | 0.66 | 25.20    | 1.27      | 24.94     | 0.68       | 0.97 |
| FR-22                                                      | S     | 4597 | 0.60  | 0.62 | 0.72 | 24.38    | 0.96      | 24.97     | 0.72       | 0.85 |
| FR-22                                                      | B     | 4609 | 0.54  | 0.56 | 0.68 | 24.43    | 0.85      | 24.98     | 0.72       | 0.78 |
| FR-08                                                      | S     | 2429 | 0.52  | 0.53 | 0.60 | 23.59    | 0.52      | 24.11     | 0.44       | 0.65 |
| FR-08                                                      | B     | 4609 | 0.05  | 0.51 | 0.60 | 24.73    | 1.23      | 24.76     | 0.73       | 0.89 |
| FR-09                                                      | S     | 4307 | 0.08  | 0.49 | 0.59 | 24.22    | 0.99      | 24.77     | 0.58       | 0.71 |
| FR-09                                                      | B     | 4609 | 0.16  | 0.51 | 0.80 | 24.42    | 1.14      | 24.59     | 0.67       | 0.85 |
| MR-10                                                      | S     | 4474 | 0.38  | 0.56 | 0.67 | 24.04    | 0.92      | 24.42     | 0.67       | 0.64 |
| FR-11R                                                     | B     | 4609 | 0.36  | 0.57 | 0.65 | 23.98    | 0.94      | 24.34     | 0.62       | 0.70 |
| SR-14                                                      | B     | 2185 | 0.64  | 0.84 | 0.90 | 22.84    | 0.40      | 23.68     | 0.52       | 0.62 |

\* S = Surface

B = Bottom

Table H-11 Temperature Comparison Percentiles, September 28 through October 13, 1999

| September 28 - October 13, 1999<br>[Julian Days 271-285] |        |              |               |            |                     |
|----------------------------------------------------------|--------|--------------|---------------|------------|---------------------|
| Stations                                                 | Depth* | Measured 50% | Simulated 50% | Difference | Absolute Mean Error |
|                                                          |        | (deg C)      | (deg C)       | (deg C)    | (deg C)             |
| FR-26                                                    | S      | 24.4         | 24.4          | 0.0        | 0.23                |
| FR-26                                                    | B      | 24.2         | 24.1          | -0.2       | 0.50                |
| FR-02                                                    | S      | 24.3         | 24.3          | 0.0        | 0.23                |
| FR-02                                                    | B      |              |               |            |                     |
| FR-04                                                    | S      | 24.2         | 24.0          | -0.2       | 0.23                |
| FR-04                                                    | B      | 24.4         | 24.2          | -0.1       | 0.25                |
| FR-21                                                    | S      | 24.1         | 23.7          | -0.3       | 0.31                |
| FR-21                                                    | B      | 24.3         | 24.2          | -0.1       | 0.18                |
| BR-05                                                    | B      | 24.2         | 24.5          | 0.3        | 0.45                |
| FR-06                                                    | S      | 24.1         | 23.9          | -0.2       | 0.36                |
| FR-06                                                    | B      | 24.4         | 24.3          | -0.1       | 0.18                |
| FR-22                                                    | S      | 23.8         | 24.3          | 0.4        | 0.46                |
| FR-22                                                    | B      | 24.2         | 24.3          | 0.1        | 0.21                |
| FR-08                                                    | S      | 23.6         | 23.8          | 0.2        | 0.39                |
| FR-08                                                    | B      | 23.9         | 24.1          | 0.2        | 0.33                |
| FR-09                                                    | S      | 23.8         | 23.9          | 0.1        | 0.43                |
| FR-09                                                    | B      | 23.8         | 23.9          | 0.1        | 0.33                |
| MR-10                                                    | S      | 23.4         | 23.5          | 0.1        | 0.37                |
| FR-11R                                                   | B      | 23.4         | 23.5          | 0.1        | 0.43                |
| SR-14                                                    | B      | 23.3         | 23.4          | 0.1        | 0.60                |

\* S = Surface

B = Bottom

Table H-12 Temperature Comparison Statistics, September 28 through October 13, 1999

| September 28 - October 13, 1999<br>[Julian Days 271-285] |       |      |       |      |      |          |           |           |            |                |
|----------------------------------------------------------|-------|------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Station                                                  | Depth | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-26                                                    | S     | 2804 | 0.03  | 0.23 | 0.29 | 24.35    | 0.40      | 24.38     | 0.34       | 0.49           |
| FR-26                                                    | B     | 2962 | -0.13 | 0.50 | 0.63 | 24.21    | 0.43      | 24.07     | 0.24       | 0.39           |
| FR-02                                                    | S     | 3015 | -0.02 | 0.23 | 0.29 | 24.28    | 0.42      | 24.26     | 0.38       | 0.55           |
| FR-02                                                    | B     | 0    |       |      |      |          |           |           |            |                |
| FR-04                                                    | S     | 3244 | -0.05 | 0.23 | 0.28 | 24.16    | 0.40      | 24.11     | 0.45       | 0.63           |
| FR-04                                                    | B     | 3257 | -0.02 | 0.25 | 0.30 | 24.28    | 0.38      | 24.27     | 0.17       | 0.45           |
| FR-21                                                    | S     | 4598 | -0.22 | 0.31 | 0.35 | 24.08    | 0.32      | 23.86     | 0.45       | 0.66           |
| FR-21                                                    | B     | 3282 | 0.02  | 0.18 | 0.21 | 24.25    | 0.31      | 24.27     | 0.23       | 0.54           |
| BR-05                                                    | B     | 2428 | 0.38  | 0.45 | 0.55 | 24.17    | 0.53      | 24.55     | 0.46       | 0.48           |
| FR-06                                                    | S     | 2722 | -0.19 | 0.36 | 0.42 | 24.15    | 0.30      | 23.96     | 0.51       | 0.47           |
| FR-06                                                    | B     | 2686 | -0.01 | 0.18 | 0.21 | 24.34    | 0.21      | 24.33     | 0.22       | 0.25           |
| FR-22                                                    | S     | 2716 | 0.44  | 0.46 | 0.56 | 23.85    | 0.42      | 24.29     | 0.23       | 0.36           |
| FR-22                                                    | B     | 2697 | 0.13  | 0.21 | 0.28 | 24.16    | 0.27      | 24.29     | 0.23       | 0.28           |
| FR-08                                                    | S     | 2757 | 0.29  | 0.39 | 0.49 | 23.56    | 0.46      | 23.85     | 0.56       | 0.50           |
| FR-08                                                    | B     | 2459 | 0.20  | 0.33 | 0.42 | 23.81    | 0.44      | 24.00     | 0.49       | 0.48           |
| FR-09                                                    | S     | 1889 | 0.04  | 0.43 | 0.51 | 23.70    | 0.43      | 23.74     | 0.65       | 0.38           |
| FR-09                                                    | B     | 2402 | 0.11  | 0.33 | 0.41 | 23.71    | 0.48      | 23.82     | 0.56       | 0.52           |
| MR-10                                                    | S     | 1916 | 0.20  | 0.37 | 0.47 | 23.42    | 0.48      | 23.62     | 0.58       | 0.47           |
| FR-11R                                                   | B     | 2443 | 0.04  | 0.43 | 0.51 | 23.50    | 0.38      | 23.54     | 0.59       | 0.27           |
| SR-14                                                    | B     | 2164 | -0.02 | 0.60 | 0.70 | 23.34    | 0.37      | 23.32     | 0.67       | 0.04           |

\* S = Surface

B = Bottom



**APPENDIX I     1997 TEMPERATURE COMPARISONS**





Table I-1 Temperature Comparison Percentiles, July 9, 1997 through October 6, 1997

| July 9 - October 6, 1997<br>[Julian Days 190-279] |        |              |               |            |                     |
|---------------------------------------------------|--------|--------------|---------------|------------|---------------------|
| Stations                                          | Depth* | Measured 50% | Simulated 50% | Difference | Absolute Mean Error |
|                                                   |        | (deg C)      | (deg C)       | (deg C)    | (deg C)             |
| FR-02                                             | S      | 28.2         | 27.0          | -1.1       | 1.0                 |
| FR-02                                             | B      | 26.2         | 26.8          | -1.4       | 1.5                 |
| FR-04                                             | S      | 28.0         | 27.2          | -0.7       | 0.8                 |
| FR-04                                             | B      | 28.2         | 27.3          | -0.8       | 1.0                 |
| BR-05                                             | B      | 27.5         | 27.5          | 0.0        | 0.5                 |
| FR-06                                             | S      | 27.4         | 26.6          | -0.8       | 0.9                 |
| FR-06                                             | B      | 27.8         | 26.9          | -0.9       | 0.9                 |
| FR-08                                             | S      | 26.9         | 26.3          | -0.6       | 0.6                 |
| FR-08                                             | B      | 27.1         | 26.6          | -0.5       | 0.6                 |
| FR-09                                             | B      | 27.0         | 26.4          | -0.6       | 0.6                 |
| MR-10                                             | B      | 26.8         | 26.7          | -0.1       | 0.5                 |
| FR-11                                             | B      | 26.6         | 25.8          | -0.7       | 0.9                 |
| SR-14                                             | B      | 26.3         | 25.6          | -0.6       | 0.8                 |

\* S = Surface

B = Bottom

Table I-2 Temperature Comparison Statistics, July 9, 1997 through October 6, 1997

| July 9 - October 6, 1997<br>[Julian Days 190-279] |        |       |       |      |      |          |           |           |            |                |
|---------------------------------------------------|--------|-------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Stations                                          | Depth* | N     | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-02                                             | S      | 9004  | -0.96 | 0.97 | 1.11 | 28.2     | 0.9       | 27.2      | 1.0        | 0.73           |
| FR-02                                             | B      | 8858  | -1.40 | 1.47 | 1.86 | 28.2     | 1.0       | 26.7      | 1.1        | 0.13           |
| FR-04                                             | S      | 8943  | -0.76 | 0.76 | 0.85 | 28.0     | 0.8       | 27.2      | 0.9        | 0.81           |
| FR-04                                             | B      | 7481  | -1.00 | 1.01 | 1.33 | 28.2     | 0.9       | 27.2      | 1.0        | 0.35           |
| BR-05                                             | B      | 8925  | 0.05  | 0.46 | 0.62 | 27.7     | 1.0       | 27.7      | 1.0        | 0.64           |
| FR-06                                             | S      | 10056 | -0.91 | 0.91 | 0.99 | 27.4     | 1.1       | 26.5      | 1.2        | 0.91           |
| FR-06                                             | B      | 9548  | -0.88 | 0.88 | 1.00 | 27.8     | 0.9       | 27.0      | 0.9        | 0.72           |
| FR-08                                             | S      | 10716 | -0.58 | 0.62 | 0.74 | 26.8     | 1.2       | 26.2      | 1.3        | 0.88           |
| FR-08                                             | B      | 11053 | -0.54 | 0.60 | 0.69 | 27.0     | 1.1       | 26.5      | 1.1        | 0.86           |
| FR-09                                             | B      | 11003 | -0.62 | 0.64 | 0.74 | 26.9     | 1.1       | 26.2      | 1.2        | 0.88           |
| MR-10                                             | B      | 8887  | -0.08 | 0.53 | 0.63 | 26.8     | 1.2       | 26.7      | 1.4        | 0.79           |
| FR-11                                             | B      | 7177  | -0.86 | 0.87 | 1.01 | 26.3     | 1.4       | 25.4      | 1.6        | 0.89           |
| SR-14                                             | B      | 11851 | -0.77 | 0.79 | 0.97 | 26.2     | 1.2       | 25.4      | 1.4        | 0.82           |

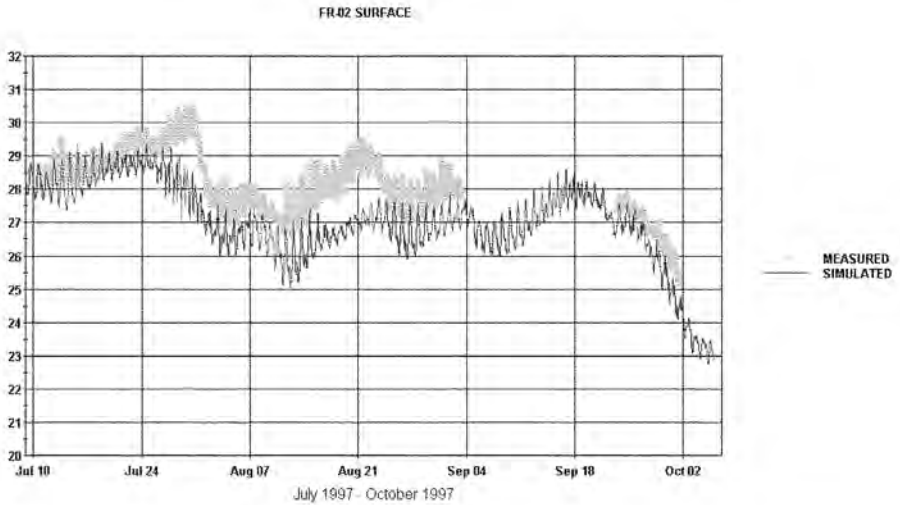


Figure I-1 Temperature (degrees C) Comparisons at FR-02 (Surface) for July 9, 1997 through October 6, 1997

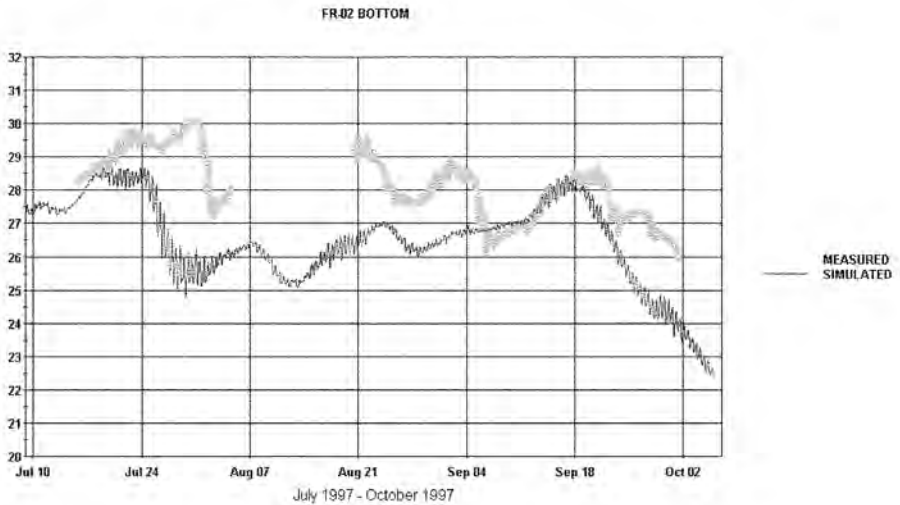


Figure I-2 Temperature (degrees C) Comparisons at FR-02 (Bottom) for July 9, 1997 through October 6, 1997

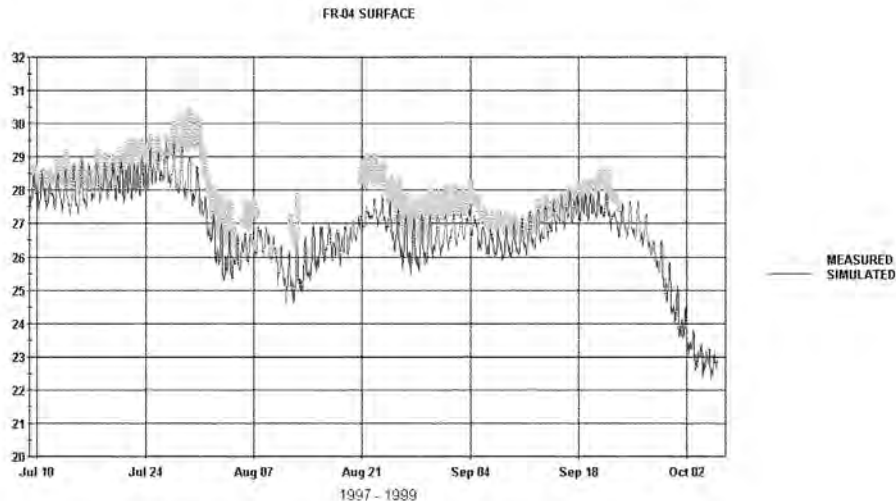


Figure I-3 Temperature (degrees C) Comparisons at FR-04 (Surface) for July 9, 1997 through October 6, 1997

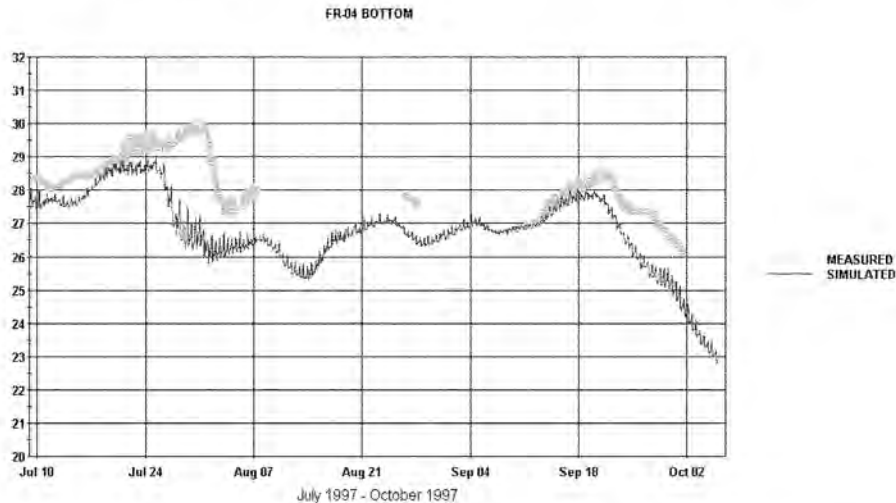


Figure I-4 Temperature (degrees C) Comparisons at FR-04 (Bottom) for July 9, 1997 through October 6, 1997

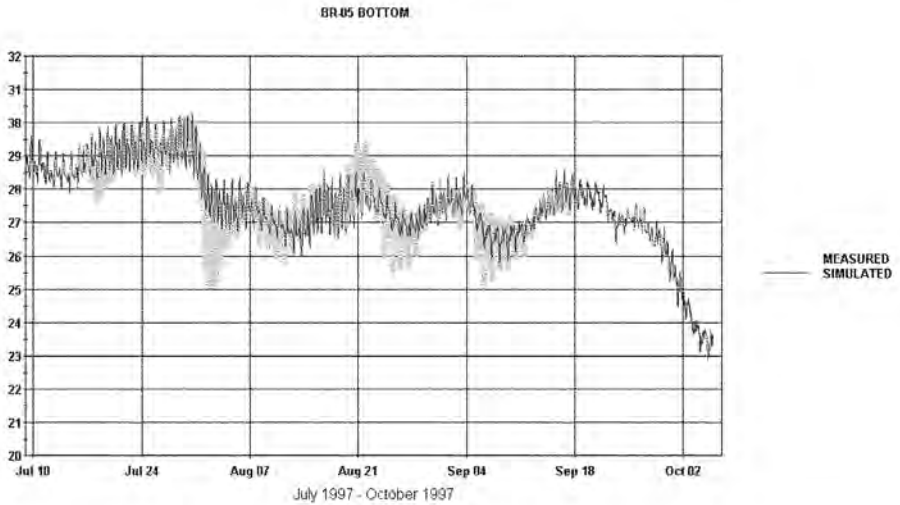


Figure I-5 Temperature (degrees C) Comparisons at BR-05 (Bottom) for July 9, 1997 through October 6, 1997

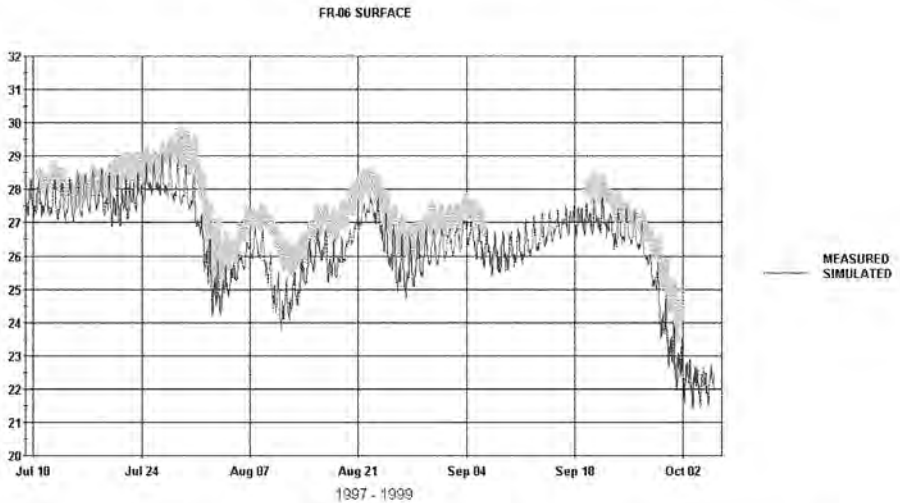


Figure I-6 Temperature (degrees C) Comparisons at FR-06 (Surface) for July 9, 1997 through October 6, 1997

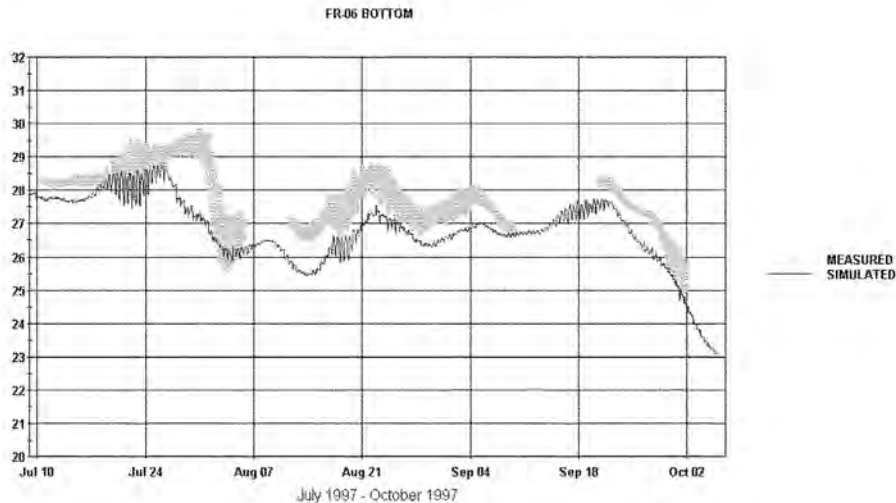


Figure I-7 Temperature (degrees C) Comparisons at FR-06 (Bottom) for July 9, 1997 through October 6, 1997

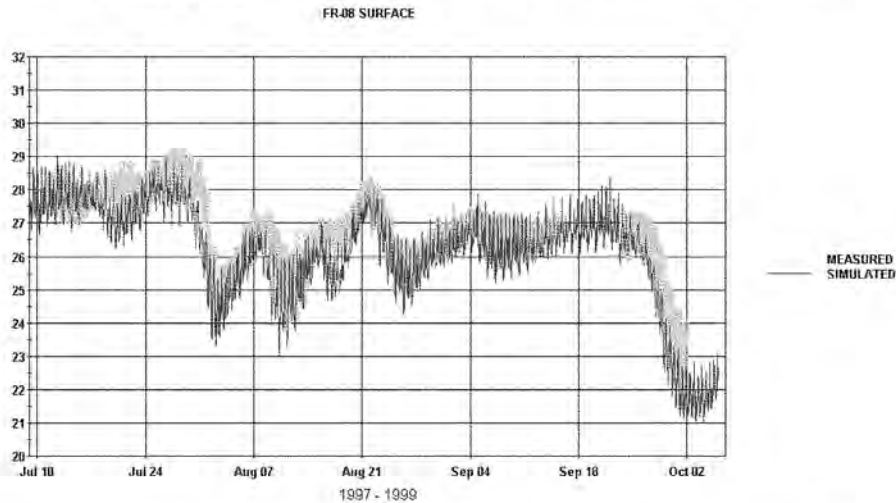


Figure I-8 Temperature (degrees C) Comparisons at FR-08 (Surface) for July 9, 1997 through October 6, 1997

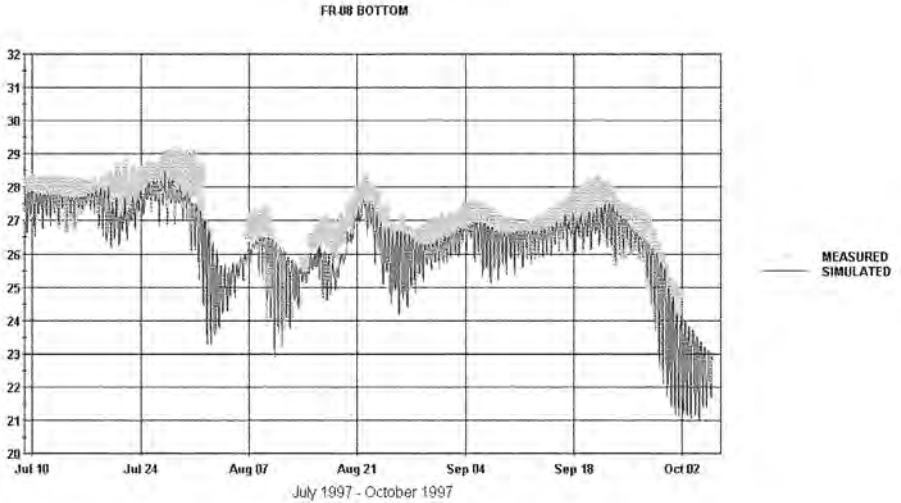


Figure I-9 Temperature (degrees C) Comparisons at FR-08 (Bottom) for July 9, 1997 through October 6, 1997

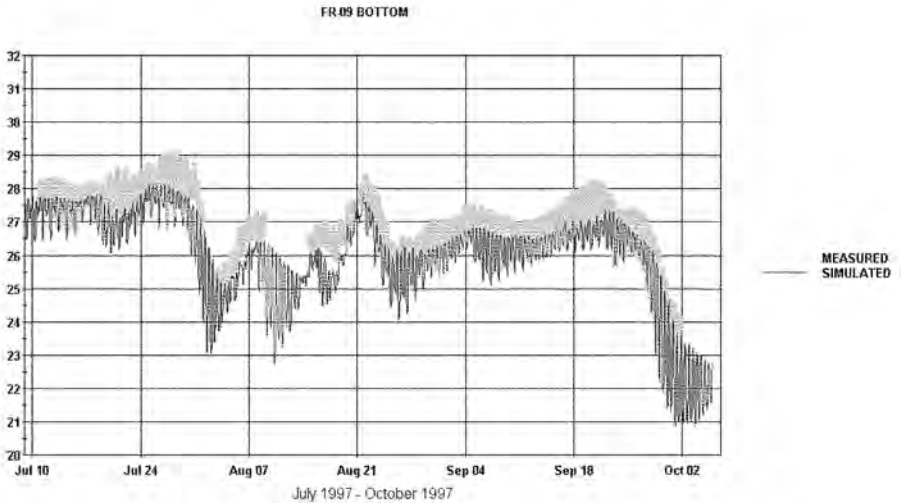


Figure I-10 Temperature (degrees C) Comparisons at FR-09 (Bottom) for July 9, 1997 through October 6, 1997

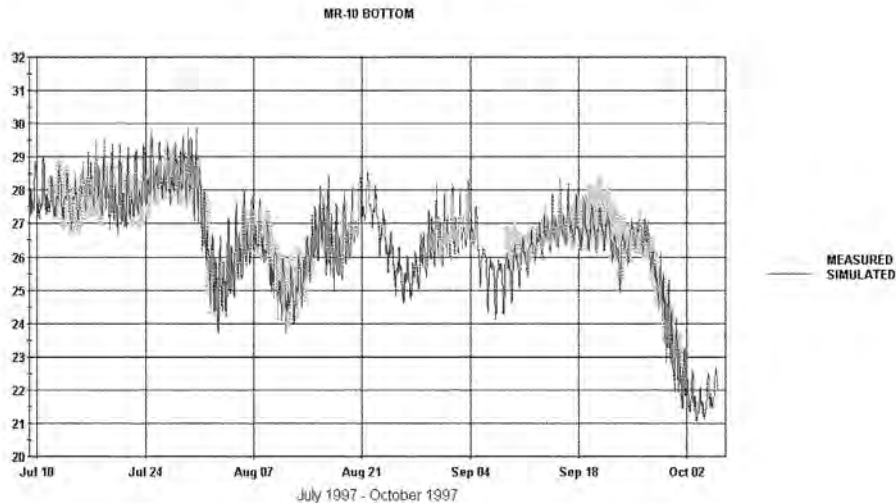


Figure I-11 Temperature (degrees C) Comparisons at MR-10 (Bottom) for July 9, 1997 through October 6, 1997

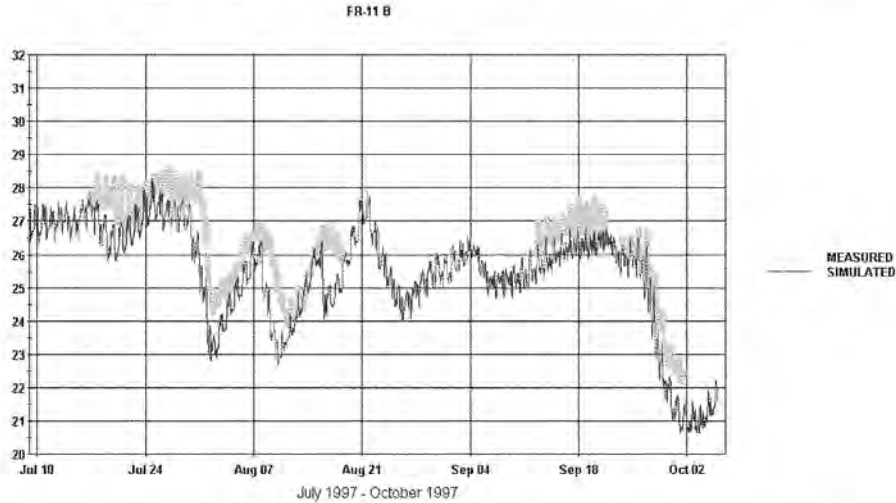


Figure I-12 Temperature (degrees C) Comparisons at FR-11 (Bottom) for July 9, 1997 through October 6, 1997

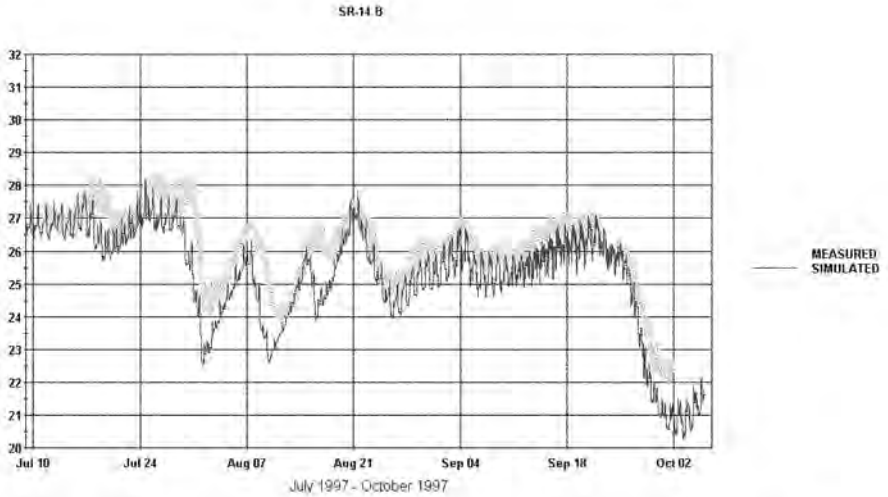


Figure I-13 Temperature (degrees C) Comparisons at SR-14 (Bottom) for July 9, 1997 through October 6, 1997

Table I-3 Temperature Comparison Percentiles, July 10, 1997 through July 23, 1997

| July 10 - July 23, 1997<br>[Julian Days 191-204] |        |              |               |            |                     |
|--------------------------------------------------|--------|--------------|---------------|------------|---------------------|
| Stations                                         | Depth* | Measured 50% | Simulated 50% | Difference | Absolute Mean Error |
|                                                  |        | (deg C)      | (deg C)       | (deg C)    | (deg C)             |
| FR-02                                            | S      | 28.7         | 28.5          | -0.2       | 0.4                 |
| FR-02                                            | B      | 28.9         | 28.4          | -0.6       | 0.7                 |
| FR-04                                            | S      | 28.5         | 28.0          | -0.5       | 0.5                 |
| FR-04                                            | B      | 28.5         | 28.0          | -0.5       | 0.5                 |
| BR-05                                            | B      | 28.8         | 29.1          | 0.3        | 0.5                 |
| FR-06                                            | S      | 28.3         | 27.6          | -0.7       | 0.6                 |
| FR-06                                            | B      | 28.3         | 27.8          | -0.5       | 0.5                 |
| FR-08                                            | S      | 27.9         | 27.5          | -0.4       | 0.5                 |
| FR-08                                            | B      | 28.0         | 27.5          | -0.5       | 0.5                 |
| FR-09                                            | B      | 27.8         | 27.3          | -0.5       | 0.6                 |
| MR-10                                            | B      | 27.9         | 27.8          | -0.1       | 0.5                 |
| FR-11                                            | B      | 27.5         | 26.8          | -0.7       | 0.7                 |
| SR-14                                            | B      | 27.2         | 26.7          | -0.5       | 0.6                 |

\* S = Surface  
B = Bottom



Table I-4 Temperature Comparison Statistics, July 10, 1997 through July 23, 1997

| July 10 - July 23, 1997<br>[Julian Days 191-204] |        |      |       |      |      |          |           |           |            |                |
|--------------------------------------------------|--------|------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Stations                                         | Depth* | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-02                                            | S      | 1932 | -0.38 | 0.40 | 0.46 | 28.8     | 0.4       | 28.4      | 0.4        | 0.64           |
| FR-02                                            | B      | 1189 | -0.65 | 0.65 | 0.76 | 29.0     | 0.4       | 28.3      | 0.2        | 0.22           |
| FR-04                                            | S      | 2078 | -0.50 | 0.51 | 0.57 | 28.6     | 0.4       | 28.1      | 0.4        | 0.54           |
| FR-04                                            | B      | 2083 | -0.52 | 0.52 | 0.58 | 28.6     | 0.4       | 28.1      | 0.5        | 0.73           |
| BR-05                                            | B      | 937  | 0.34  | 0.49 | 0.62 | 28.8     | 0.5       | 29.1      | 0.4        | 0.15           |
| FR-06                                            | S      | 1927 | -0.62 | 0.64 | 0.73 | 28.3     | 0.3       | 27.7      | 0.4        | 0.21           |
| FR-06                                            | B      | 1928 | -0.49 | 0.49 | 0.53 | 28.4     | 0.3       | 27.9      | 0.3        | 0.60           |
| FR-08                                            | S      | 1870 | -0.40 | 0.51 | 0.63 | 27.9     | 0.4       | 27.5      | 0.5        | 0.12           |
| FR-08                                            | B      | 2109 | -0.50 | 0.51 | 0.59 | 27.9     | 0.4       | 27.4      | 0.4        | 0.43           |
| FR-09                                            | B      | 1913 | -0.53 | 0.56 | 0.66 | 27.8     | 0.4       | 27.2      | 0.4        | 0.32           |
| MR-10                                            | B      | 1805 | 0.08  | 0.48 | 0.60 | 27.8     | 0.4       | 27.9      | 0.6        | 0.13           |
| FR-11                                            | B      | 1068 | -0.70 | 0.72 | 0.84 | 27.5     | 0.4       | 26.8      | 0.5        | 0.27           |
| SR-14                                            | B      | 1823 | -0.52 | 0.59 | 0.73 | 27.2     | 0.4       | 26.7      | 0.5        | 0.07           |

\* S = Surface  
B = Bottom

Table I-5 Temperature Comparison Percentiles, July 24, 1997 through August 7, 1997

| July 24 - August 7, 1997<br>[Julian Days 205-219] |        |              |               |            |                     |
|---------------------------------------------------|--------|--------------|---------------|------------|---------------------|
| Stations                                          | Depth* | Measured 50% | Simulated 50% | Difference | Absolute Mean Error |
|                                                   |        | (deg C)      | (deg C)       | (deg C)    | (deg C)             |
| FR-02                                             | S      | 29.1         | 27.4          | -1.7       | 1.1                 |
| FR-02                                             | B      | 29.4         | 25.9          | -3.5       | 2.9                 |
| FR-04                                             | S      | 28.9         | 27.7          | -1.2       | 1.0                 |
| FR-04                                             | B      | 29.4         | 26.5          | -2.8       | 2.0                 |
| BR-05                                             | B      | 28.4         | 28.5          | 0.1        | 0.6                 |
| FR-06                                             | S      | 28.2         | 26.9          | -1.3       | 1.0                 |
| FR-06                                             | B      | 29.1         | 27.3          | -1.8       | 1.2                 |
| FR-08                                             | S      | 27.7         | 26.5          | -1.2       | 0.7                 |
| FR-08                                             | B      | 28.1         | 27.4          | -0.7       | 0.8                 |
| FR-09                                             | B      | 27.4         | 26.3          | -1.0       | 0.8                 |
| MR-10                                             | B      | 27.3         | 27.6          | 0.3        | 0.6                 |
| FR-11                                             | B      | 27.2         | 26.0          | -1.1       | 1.0                 |
| SR-14                                             | B      | 26.8         | 25.6          | -1.2       | 1.1                 |

\* S = Surface  
B = Bottom

Table I-6 Temperature Comparison Statistics, July 24, 1997 through August 7, 1997

| July 24 - August 7, 1997<br>[Julian Days 205-219] |        |      |       |      |      |          |           |           |            |                |
|---------------------------------------------------|--------|------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Stations                                          | Depth* | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-02                                             | S      | 2137 | -1.12 | 1.12 | 1.23 | 28.7     | 1.0       | 27.6      | 0.9        | 0.73           |
| FR-02                                             | B      | 1649 | -2.87 | 2.87 | 3.13 | 29.1     | 0.9       | 26.2      | 1.0        | 0.01           |
| FR-04                                             | S      | 1912 | -1.03 | 1.03 | 1.09 | 28.4     | 1.1       | 27.4      | 1.1        | 0.91           |
| FR-04                                             | B      | 1958 | -1.96 | 1.96 | 2.18 | 28.9     | 0.9       | 27.0      | 0.9        | 0.19           |
| BR-05                                             | B      | 2157 | 0.23  | 0.62 | 0.87 | 28.2     | 1.3       | 28.4      | 1.0        | 0.58           |
| FR-06                                             | S      | 2158 | -0.97 | 0.97 | 1.02 | 27.8     | 1.3       | 26.8      | 1.3        | 0.94           |
| FR-06                                             | B      | 1832 | -1.15 | 1.17 | 1.40 | 28.5     | 1.2       | 27.3      | 0.9        | 0.54           |
| FR-08                                             | S      | 2149 | -0.74 | 0.74 | 0.83 | 27.2     | 1.4       | 26.5      | 1.4        | 0.92           |
| FR-08                                             | B      | 1605 | -0.67 | 0.80 | 0.88 | 27.7     | 1.2       | 27.0      | 1.1        | 0.79           |
| FR-09                                             | B      | 2155 | -0.78 | 0.82 | 0.90 | 27.1     | 1.4       | 26.3      | 1.4        | 0.90           |
| MR-10                                             | B      | 2147 | 0.10  | 0.63 | 0.73 | 27.1     | 1.4       | 27.2      | 1.4        | 0.75           |
| FR-11                                             | B      | 2158 | -0.96 | 0.96 | 1.08 | 26.8     | 1.3       | 25.8      | 1.4        | 0.88           |
| SR-14                                             | B      | 2156 | -1.13 | 1.13 | 1.29 | 26.7     | 1.3       | 25.5      | 1.4        | 0.81           |

\* S = Surface

B = Bottom

Table I-7 Temperature Comparison Percentiles, August 8, 1997 through August 22, 1997

| August 8 - August 22, 1997<br>[Julian Days 220-234] |        |              |               |            |                     |
|-----------------------------------------------------|--------|--------------|---------------|------------|---------------------|
| Stations                                            | Depth* | Measured 50% | Simulated 50% | Difference | Absolute Mean Error |
|                                                     |        | (deg C)      | (deg C)       | (deg C)    | (deg C)             |
| FR-02                                               | S      | 27.9         | 26.6          | -1.3       | 1.5                 |
| FR-02                                               | B      | 29.2         | 26.6          | -2.6       | 2.6                 |
| FR-04                                               | S      | 28.4         | 27.1          | -1.3       | 1.4                 |
| FR-04                                               | B      |              |               |            |                     |
| BR-05                                               | B      | 27.5         | 27.2          | -0.3       | 0.5                 |
| FR-06                                               | S      | 27.0         | 25.9          | -1.2       | 1.2                 |
| FR-06                                               | B      | 27.2         | 26.1          | -1.1       | 1.2                 |
| FR-08                                               | S      | 26.6         | 25.8          | -0.8       | 0.8                 |
| FR-08                                               | B      | 26.8         | 25.9          | -0.9       | 0.8                 |
| FR-09                                               | B      | 26.8         | 25.9          | -0.9       | 0.9                 |
| MR-10                                               | B      | 26.2         | 25.9          | -0.3       | 0.5                 |
| FR-11                                               | B      | 25.8         | 24.6          | -1.2       | 1.0                 |
| SR-14                                               | B      | 26.1         | 24.9          | -1.2       | 0.9                 |

\* S = Surface

B = Bottom

Table I-8 Temperature Comparison Statistics, August 8, 1997 through August 22, 1997

| August 8 - August 22, 1997<br>[Julian Days 220-234] |        |      |       |      |      |          |           |           |            |                |
|-----------------------------------------------------|--------|------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Stations                                            | Depth* | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-02                                               | S      | 2154 | -1.45 | 1.45 | 1.52 | 28.0     | 0.7       | 26.5      | 0.5        | 0.63           |
| FR-02                                               | B      | 366  | -2.63 | 2.63 | 2.65 | 29.2     | 0.2       | 26.6      | 0.2        | 0.25           |
| FR-04                                               | S      | 481  | -1.41 | 1.41 | 1.42 | 28.0     | 0.9       | 26.6      | 0.9        | 0.95           |
| FR-04                                               | B      | 0    | 0.00  | 0.00 | 0.00 | 0.0      | 0.0       | 0.0       | 0.0        | 0.00           |
| BR-05                                               | B      | 2158 | -0.28 | 0.53 | 0.63 | 27.5     | 0.7       | 27.3      | 0.5        | 0.37           |
| FR-06                                               | S      | 2146 | -1.15 | 1.15 | 1.21 | 27.0     | 0.8       | 25.9      | 0.9        | 0.83           |
| FR-06                                               | B      | 1618 | -1.20 | 1.20 | 1.22 | 27.4     | 0.6       | 26.2      | 0.6        | 0.88           |
| FR-08                                               | S      | 2128 | -0.75 | 0.78 | 0.91 | 26.5     | 0.9       | 25.8      | 1.0        | 0.75           |
| FR-08                                               | B      | 1622 | -0.78 | 0.81 | 0.91 | 26.7     | 0.9       | 25.9      | 1.0        | 0.78           |
| FR-09                                               | B      | 1213 | -0.90 | 0.90 | 1.00 | 26.9     | 0.5       | 26.0      | 0.8        | 0.74           |
| MR-10                                               | B      | 1650 | -0.18 | 0.54 | 0.66 | 26.1     | 0.7       | 25.9      | 0.9        | 0.50           |
| FR-11                                               | B      | 1514 | -1.02 | 1.04 | 1.26 | 25.5     | 0.9       | 24.5      | 0.9        | 0.43           |
| SR-14                                               | B      | 2157 | -0.90 | 0.92 | 1.18 | 25.9     | 1.0       | 25.0      | 1.3        | 0.63           |

\* S = Surface

B = Bottom

Table I-9 Temperature Comparison Percentiles, August 23, 1997 through September 6, 1997

| August 23 - September 6, 1997<br>[Julian Days 235-249] |        |              |               |            |                     |
|--------------------------------------------------------|--------|--------------|---------------|------------|---------------------|
| Stations                                               | Depth* | Measured 50% | Simulated 50% | Difference | Absolute Mean Error |
|                                                        |        | (deg C)      | (deg C)       |            |                     |
| FR-02                                                  | S      | 27.9         | 26.9          | -1.0       | 1.0                 |
| FR-02                                                  | B      | 28.1         | 26.7          | -1.4       | 1.5                 |
| FR-04                                                  | S      | 27.5         | 26.7          | -0.8       | 0.9                 |
| FR-04                                                  | B      | 27.7         | 26.6          | -1.1       | 1.1                 |
| BR-05                                                  | B      | 27.4         | 27.3          | -0.1       | 0.4                 |
| FR-06                                                  | S      | 27.1         | 26.3          | -0.8       | 0.8                 |
| FR-06                                                  | B      | 27.6         | 26.8          | -0.8       | 0.9                 |
| FR-08                                                  | S      | 26.5         | 26.1          | -0.4       | 0.4                 |
| FR-08                                                  | B      | 26.7         | 26.3          | -0.4       | 0.5                 |
| FR-09                                                  | B      | 26.5         | 26.0          | -0.4       | 0.5                 |
| MR-10                                                  | B      |              |               |            |                     |
| FR-11                                                  | B      |              |               |            |                     |
| SR-14                                                  | B      | 25.9         | 25.2          | -0.7       | 0.6                 |

\* S = Surface

B = Bottom

Table I-10 Temperature Comparison Statistics, August 23, 1997 through September 6, 1997

| August 23 - September 6, 1997<br>(Julian Days 235-249) |        |      |       |      |      |          |           |           |            |                |
|--------------------------------------------------------|--------|------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Stations                                               | Depth* | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-02                                                  | S      | 1632 | -1.00 | 1.00 | 1.03 | 27.9     | 0.5       | 26.9      | 0.4        | 0.73           |
| FR-02                                                  | B      | 2149 | -1.46 | 1.49 | 1.57 | 28.1     | 0.6       | 26.6      | 0.3        | 0.06           |
| FR-04                                                  | S      | 2160 | -0.86 | 0.86 | 0.90 | 27.5     | 0.4       | 26.6      | 0.5        | 0.69           |
| FR-04                                                  | B      | 275  | -1.13 | 1.13 | 1.14 | 27.7     | 0.1       | 26.6      | 0.1        | 0.42           |
| BR-05                                                  | B      | 2158 | 0.05  | 0.39 | 0.48 | 27.2     | 0.6       | 27.3      | 0.4        | 0.37           |
| FR-06                                                  | S      | 2043 | -0.82 | 0.82 | 0.87 | 27.1     | 0.5       | 26.2      | 0.6        | 0.77           |
| FR-06                                                  | B      | 2147 | -0.88 | 0.88 | 0.90 | 27.6     | 0.4       | 26.8      | 0.3        | 0.69           |
| FR-08                                                  | S      | 2136 | -0.38 | 0.42 | 0.48 | 26.5     | 0.6       | 26.1      | 0.6        | 0.79           |
| FR-08                                                  | B      | 2153 | -0.42 | 0.47 | 0.52 | 26.6     | 0.7       | 26.2      | 0.6        | 0.79           |
| FR-09                                                  | B      | 2156 | -0.52 | 0.52 | 0.57 | 26.4     | 0.7       | 25.9      | 0.6        | 0.86           |
| MR-10                                                  | B      | 0    | 0.00  | 0.00 | 0.00 | 0.0      | 0.0       | 0.0       | 0.0        | 0.00           |
| FR-11                                                  | B      | 0    | 0.00  | 0.00 | 0.00 | 0.0      | 0.0       | 0.0       | 0.0        | 0.00           |
| SR-14                                                  | B      | 2160 | -0.63 | 0.64 | 0.71 | 25.9     | 0.6       | 25.3      | 0.6        | 0.73           |

\* S = Surface

B = Bottom

Table I-11 Temperature Comparison Percentiles, September 7, 1997 through September 20, 1997

| September 7 - September 20, 1997<br>(Julian Days 250-263) |        |              |               |            |                     |
|-----------------------------------------------------------|--------|--------------|---------------|------------|---------------------|
| Stations                                                  | Depth* | Measured 50% | Simulated 50% | Difference | Absolute Mean Error |
|                                                           |        | (deg C)      | (deg C)       | (deg C)    | (deg C)             |
| FR-02                                                     | S      |              |               |            |                     |
| FR-02                                                     | B      | 27.7         | 27.5          | -0.2       | 0.3                 |
| FR-04                                                     | S      | 27.4         | 27.0          | -0.4       | 0.5                 |
| FR-04                                                     | B      | 27.7         | 27.5          | -0.2       | 0.2                 |
| BR-05                                                     | B      | 27.0         | 27.0          | 0.0        | 0.2                 |
| FR-06                                                     | S      | 28.1         | 27.1          | -1.0       | 1.0                 |
| FR-06                                                     | B      | 27.1         | 26.7          | -0.4       | 0.4                 |
| FR-08                                                     | S      | 26.8         | 26.2          | -0.6       | 0.5                 |
| FR-08                                                     | B      | 27.0         | 26.6          | -0.4       | 0.5                 |
| FR-09                                                     | B      | 27.0         | 26.5          | -0.5       | 0.6                 |
| MR-10                                                     | B      | 26.8         | 26.6          | -0.2       | 0.5                 |
| FR-11                                                     | B      | 26.9         | 26.1          | -0.8       | 0.7                 |
| SR-14                                                     | B      | 26.4         | 25.8          | -0.6       | 0.7                 |

\* S = Surface

B = Bottom

Table I-12 Temperature Comparison Statistics, September 7, 1997 through September 20, 1997

| September 7 - September 20, 1997<br>(Julian Days 260-263) |        |      |       |      |      |          |           |           |            |                |
|-----------------------------------------------------------|--------|------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Stations                                                  | Depth* | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-02                                                     | S      | 0    |       |      |      |          |           |           |            |                |
| FR-02                                                     | B      | 2012 | -0.01 | 0.26 | 0.36 | 27.5     | 0.7       | 27.5      | 0.5        | 0.78           |
| FR-04                                                     | S      | 1963 | -0.50 | 0.50 | 0.55 | 27.4     | 0.5       | 26.9      | 0.6        | 0.81           |
| FR-04                                                     | B      | 1672 | -0.21 | 0.22 | 0.28 | 27.6     | 0.6       | 27.4      | 0.4        | 0.94           |
| BR-05                                                     | B      | 1519 | 0.08  | 0.22 | 0.28 | 27.0     | 0.5       | 27.1      | 0.6        | 0.79           |
| FR-06                                                     | S      | 226  | -0.97 | 0.97 | 0.99 | 28.1     | 0.2       | 27.2      | 0.3        | 0.43           |
| FR-06                                                     | B      | 466  | -0.41 | 0.41 | 0.45 | 27.2     | 0.5       | 26.8      | 0.3        | 0.92           |
| FR-08                                                     | S      | 1249 | -0.45 | 0.49 | 0.55 | 26.7     | 0.4       | 26.2      | 0.4        | 0.49           |
| FR-08                                                     | B      | 2014 | -0.54 | 0.55 | 0.59 | 27.1     | 0.5       | 26.5      | 0.4        | 0.78           |
| FR-09                                                     | B      | 2014 | -0.61 | 0.61 | 0.66 | 27.0     | 0.6       | 26.4      | 0.4        | 0.87           |
| MR-10                                                     | B      | 1770 | -0.32 | 0.49 | 0.56 | 26.9     | 0.5       | 26.6      | 0.6        | 0.48           |
| FR-11                                                     | B      | 1213 | -0.74 | 0.74 | 0.77 | 26.9     | 0.4       | 26.1      | 0.3        | 0.72           |
| SR-14                                                     | B      | 2014 | -0.65 | 0.65 | 0.72 | 26.4     | 0.5       | 25.7      | 0.5        | 0.64           |

\* S = Surface

B = Bottom

Table I-13 Temperature Comparison Percentiles, September 21, 1997 through October 6, 1997

| September 21 - October 6, 1997<br>(Julian Days 264-279) |        |              |               |            |                     |
|---------------------------------------------------------|--------|--------------|---------------|------------|---------------------|
| Stations                                                | Depth* | Measured 50% | Simulated 50% | Difference | Absolute Mean Error |
|                                                         |        | (deg C)      | (deg C)       | (deg C)    | (deg C)             |
| FR-02                                                   | S      |              |               |            |                     |
| FR-02                                                   | B      | 27.2         | 25.0          | -2.2       | 1.9                 |
| FR-04                                                   | S      | 27.9         | 27.2          | -0.7       | 0.7                 |
| FR-04                                                   | B      | 27.4         | 25.9          | -1.5       | 1.3                 |
| BR-05                                                   | B      | 0.0          | 0.0           | 0.0        | 0.0                 |
| FR-06                                                   | S      | 27.1         | 26.3          | -0.7       | 0.9                 |
| FR-06                                                   | B      | 27.4         | 26.3          | -1.1       | 0.8                 |
| FR-08                                                   | S      | 26.8         | 26.2          | -0.6       | 0.5                 |
| FR-08                                                   | B      | 26.6         | 26.3          | -0.3       | 0.5                 |
| FR-09                                                   | B      | 26.3         | 26.2          | -0.1       | 0.5                 |
| MR-10                                                   | B      | 26.2         | 26.1          | 0.0        | 0.5                 |
| FR-11                                                   | B      | 25.2         | 24.7          | -0.5       | 0.8                 |
| SR-14                                                   | B      | 25.7         | 25.0          | -0.6       | 0.8                 |

\* S = Surface

B = Bottom

Table I-14 Temperature Comparison Statistics, September 21, 1997 through October 6, 1997

| September 21 – October 6, 1997<br>(Julian Days 264-279) |        |      |       |      |      |             |              |              |               |                |
|---------------------------------------------------------|--------|------|-------|------|------|-------------|--------------|--------------|---------------|----------------|
| Stations                                                | Depth* | N    | ME    | AME  | RMS  | Mean<br>Obs | StDev<br>Obs | Mean<br>Pred | StDev<br>Pred | R <sup>2</sup> |
| FR-02                                                   | S      | 1152 | -0.69 | 0.69 | 0.75 | 26.9        | 0.6          | 26.2         | 0.9           | 0.97           |
| FR-02                                                   | B      | 1497 | -1.87 | 1.87 | 1.96 | 27.2        | 0.6          | 25.3         | 1.0           | 0.77           |
| FR-04                                                   | S      | 353  | -0.73 | 0.73 | 0.75 | 27.9        | 0.3          | 27.2         | 0.3           | 0.80           |
| FR-04                                                   | B      | 1495 | -1.29 | 1.29 | 1.34 | 27.3        | 0.6          | 26.0         | 0.9           | 0.91           |
| BR-05                                                   | B      | 0    |       |      |      |             |              |              |               |                |
| FR-06                                                   | S      | 1560 | -0.95 | 0.95 | 1.04 | 26.6        | 1.2          | 25.6         | 1.5           | 0.97           |
| FR-06                                                   | B      | 1561 | -0.84 | 0.84 | 0.87 | 27.2        | 0.8          | 26.4         | 0.9           | 0.93           |
| FR-08                                                   | S      | 1249 | -0.45 | 0.49 | 0.55 | 26.7        | 0.4          | 26.2         | 0.4           | 0.49           |
| FR-08                                                   | B      | 1555 | -0.40 | 0.53 | 0.62 | 26.1        | 1.5          | 25.7         | 1.6           | 0.91           |
| FR-09                                                   | B      | 1557 | -0.45 | 0.51 | 0.65 | 25.8        | 1.6          | 25.4         | 1.8           | 0.94           |
| MR-10                                                   | B      | 1518 | -0.13 | 0.49 | 0.59 | 25.7        | 1.4          | 25.5         | 1.5           | 0.85           |
| FR-11                                                   | B      | 1227 | -0.75 | 0.75 | 0.87 | 24.8        | 1.6          | 24.0         | 2.0           | 0.99           |
| SR-14                                                   | B      | 1546 | -0.73 | 0.77 | 0.93 | 24.8        | 1.6          | 24.1         | 2.1           | 0.97           |

\* S = Surface  
B = Bottom

**APPENDIX J    1999 SALINITY COMPARISONS**





Table J-1 Summary Percentiles for Salinity (ppt) for July 31, 1999 through October 13, 1999

| July 31 - October 13, 1999<br>(Julian Days 212-285) |                    |           |      |      |          |      |      |            |      |      |                    |        |       |                        |
|-----------------------------------------------------|--------------------|-----------|------|------|----------|------|------|------------|------|------|--------------------|--------|-------|------------------------|
| Stations                                            | Depth <sup>1</sup> | Simulated |      |      | Measured |      |      | Difference |      |      | Percent Difference |        |       | Evaluation<br>Criteria |
|                                                     |                    | 10%       | 50%  | 90%  | 10%      | 50%  | 90%  | 10%        | 50%  | 90%  | 10%                | 50%    | 90%   |                        |
| FR-26                                               | S                  | 15.0      | 23.5 | 26.6 | 19.5     | 26.5 | 30.6 | -4.5       | -3.0 | -4.2 | 23.0               | 11.2   | 13.5  | >5                     |
| FR-26                                               | B                  | 30.7      | 33.2 | 34.0 | 36.7     | 30.6 | 33.6 | -4.0       | -7.5 | 0.5  | -35.1              | -3.3   | -1.4  | >5                     |
| FR-02                                               | S                  | 10.6      | 15.4 | 25.3 | 12.8     | 16.6 | 26.5 | -2.2       | -3.3 | -2.2 | 12.2               | 17.5   | 0.7   | >5                     |
| FR-02                                               | B                  | 28.6      | 32.3 | 33.6 | 26.0     | 31.4 | 33.4 | -2.6       | 0.8  | 0.2  | -5.9               | -2.6   | -0.7  | >5                     |
| SC-03                                               | B                  | 14.4      | 16.6 | 19.2 | 15.2     | 18.2 | 20.7 | -0.8       | -1.6 | -1.4 | -5.2               | 8.9    | 7.0   | >5                     |
| FR-04                                               | S                  | 6.5       | 9.3  | 13.9 | 8.5      | 12.5 | 17.7 | -2.1       | -3.1 | -3.3 | 24.3               | 25.2   | 21.5  | >5                     |
| FR-04                                               | B                  | 17.4      | 21.3 | 27.1 | 13.5     | 16.1 | 26.7 | -3.9       | 3.2  | 0.4  | -28.8              | -17.5  | -1.3  | >5                     |
| FR-21                                               | S                  | 3.7       | 6.5  | 10.3 | 5.0      | 7.8  | 12.8 | -1.3       | -1.2 | -2.5 | 26.0               | 16.0   | 19.7  | >5                     |
| FR-21                                               | B                  | 13.5      | 17.2 | 22.4 | 10.7     | 15.8 | 22.7 | -2.8       | -1.4 | -0.3 | -26.3              | -3.7   | -1.2  | >5                     |
| BR-05                                               | B                  | 6.4       | 10.2 | 15.4 | 2.0      | 7.5  | 13.7 | 4.4        | 2.7  | 1.7  | -216.8             | -36.0  | -12.1 | >5                     |
| FR-05                                               | S                  | 2.3       | 4.5  | 9.0  | 3.0      | 5.4  | 10.5 | -0.7       | -0.9 | -1.5 | 21.8               | 16.8   | 14.6  | >5                     |
| FR-06                                               | B                  | 12.0      | 16.7 | 23.1 | 8.1      | 14.2 | 23.1 | -3.9       | 2.5  | 0.0  | -47.7              | -17.5  | -0.0  | >5                     |
| FR-22                                               | S                  | 0.5       | 2.5  | 5.5  | 0.6      | 2.8  | 7.3  | 0.1        | -0.4 | -1.7 | -22.3              | 13.2   | 24.0  | <5                     |
| FR-22                                               | B                  | 6.9       | 11.1 | 15.9 | 2.7      | 7.6  | 12.8 | 4.2        | 3.5  | -3.1 | -156.3             | -46.0  | -23.9 | >5                     |
| BR-07                                               | S                  | 0.9       | 2.2  | 5.0  | 0.2      | 0.7  | 3.9  | 0.7        | -1.4 | -1.2 | -303.3             | -193.4 | -29.9 | <5                     |
| FR-08                                               | S                  | 0.3       | 1.9  | 4.7  | 0.1      | 0.9  | 5.5  | 0.2        | -1.0 | -0.8 | -328.7             | -114.9 | 13.9  | <5                     |
| FR-08                                               | B                  | 0.5       | 5.4  | 19.7 | 0.1      | 4.6  | 13.3 | 0.3        | 0.8  | 6.4  | -227.2             | -18.2  | -48.5 | <5                     |
| LRR-15                                              | S                  | 0.1       | 0.5  | 1.5  | 0.1      | 0.3  | 1.0  | 0.0        | 0.2  | 0.5  | -8.2               | -75.4  | -47.9 | <5                     |
| FR-09                                               | S                  | 0.1       | 1.3  | 3.9  | 0.1      | 0.9  | 6.2  | 0.1        | -0.4 | -1.3 | -153.2             | -45.6  | 25.0  | <5                     |
| FR-09                                               | B                  | 0.2       | 2.7  | 12.3 | 0.1      | 1.6  | 8.1  | 0.1        | -1.0 | -3.2 | -54.7              | -54.9  | -34.7 | <5                     |
| MR-10                                               | S                  | 0.4       | 1.1  | 3.2  | 0.2      | 1.1  | 3.9  | 0.1        | 0.0  | -0.7 | -46.3              | 3.1    | 17.9  | <5                     |
| FR-11R                                              | B                  | 0.0       | 0.2  | 7.0  | 0.0      | 0.1  | 4.1  | 0.0        | 0.1  | -2.9 | 98.0               | -144.6 | -29.5 | <5                     |
| MR-12R                                              | S                  | 0.1       | -0.4 | 1.1  | 0.1      | 0.3  | 2.2  | 0.0        | 0.1  | -1.1 | -30.1              | -36.6  | 48.1  | <5                     |
| SR-14                                               | B                  | 0.0       | 0.0  | 0.0  | 0.0      | 0.1  | 0.1  | 0.0        | 0.0  | 0.0  | 100.0              | 99.9   | 81.2  | <5                     |
| USGS02138920<br>(Houlihan Bridge)                   | M                  | 0.1       | 2.2  | 7.3  | 0.1      | 1.5  | 5.3  | 0.1        | 0.8  | 1.9  | -99.7              | -52.6  | -35.8 | <5                     |
| USGS02195540<br>(I-95)                              | M                  | 0.0       | 0.0  | 0.0  | 0.0      | 0.0  | 0.1  | 0.0        | 0.0  | 0.0  | 100.0              | 100.0  | 89.8  | <5                     |
| USGS021669784<br>(Lucas Canal)                      | M                  | 0.0       | 0.1  | 0.4  | 0.1      | 0.2  | 0.4  | -0.1       | -0.1 | 0.0  | 65.4               | 40.7   | -4.9  | <5                     |
| USGS02198191<br>(US F&W Docks)                      | M                  | 0.1       | 0.3  | 0.9  | 0.1      | 0.2  | 0.6  | 0.0        | 0.1  | -0.3 | 32.9               | -39.3  | -53.7 | <5                     |

<sup>1</sup> S = Surface  
B = Bottom  
M = Mid-Depth

Statistic Applicable for Criteria  
Meets Criteria

Table J-2 Summary Statistics for Salinity (ppt) for July 31, 1999 through October 13, 1999

| July 31 - October 13, 1999<br>(Julian Days 212-285) |        |       |       |      |      |          |           |           |            |                |
|-----------------------------------------------------|--------|-------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Station                                             | Depth* | N     | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-26                                               | S      | 13592 | -3.77 | 4.14 | 4.66 | 25.68    | 4.40      | 21.91     | 4.60       | 0.67           |
| FR-26                                               | B      | 16580 | 2.34  | 2.75 | 3.52 | 30.17    | 2.86      | 32.51     | 1.92       | 0.20           |
| FR-02                                               | S      | 10346 | -2.02 | 3.71 | 4.37 | 18.90    | 4.72      | 16.89     | 5.46       | 0.52           |
| FR-02                                               | B      | 2225  | 1.11  | 2.33 | 3.17 | 30.58    | 2.79      | 31.68     | 1.98       | 0.07           |
| SC-03                                               | B      | 15516 | -1.38 | 2.10 | 2.59 | 18.08    | 2.11      | 16.69     | 1.82       | 0.15           |
| FR-04                                               | S      | 14937 | -3.00 | 3.10 | 3.74 | 12.85    | 3.48      | 9.85      | 2.83       | 0.59           |
| FR-04                                               | B      | 12965 | 2.84  | 3.31 | 4.06 | 18.98    | 4.69      | 21.62     | 3.43       | 0.62           |
| FR-21                                               | S      | 18683 | 1.62  | 2.12 | 2.69 | 8.43     | 3.09      | 6.81      | 2.51       | 0.55           |
| FR-21                                               | B      | 13045 | 1.26  | 2.95 | 3.69 | 16.12    | 4.45      | 17.39     | 3.16       | 0.40           |
| BR-05                                               | B      | 11817 | 2.87  | 3.35 | 4.09 | 7.80     | 4.18      | 10.67     | 3.27       | 0.52           |
| FR-06                                               | S      | 11886 | -0.89 | 1.44 | 1.80 | 6.03     | 2.77      | 5.15      | 2.56       | 0.69           |
| FR-06                                               | B      | 14956 | 2.14  | 2.93 | 3.60 | 14.97    | 5.39      | 17.11     | 4.12       | 0.72           |
| FR-22                                               | S      | 18949 | -0.66 | 1.16 | 1.61 | 3.53     | 2.75      | 2.87      | 1.88       | 0.75           |
| FR-22                                               | B      | 13918 | 3.75  | 4.02 | 4.74 | 7.68     | 3.85      | 11.43     | 3.51       | 0.48           |
| BR-07                                               | S      | 18038 | 1.18  | 1.74 | 2.20 | 1.48     | 1.89      | 2.66      | 1.73       | 0.23           |
| FR-08                                               | S      | 11920 | 0.19  | 1.27 | 1.76 | 2.11     | 2.75      | 2.30      | 1.82       | 0.61           |
| FR-08                                               | B      | 8385  | 2.29  | 3.84 | 5.50 | 5.44     | 4.70      | 7.73      | 7.02       | 0.48           |
| FR-15                                               | S      | 18893 | -0.21 | 1.29 | 1.88 | 1.92     | 2.40      | 1.72      | 1.68       | 0.40           |
| FR-09                                               | S      | 18499 | 1.14  | 2.08 | 3.20 | 3.30     | 3.98      | 4.44      | 4.92       | 0.63           |
| FR-09                                               | B      | 15511 | -0.17 | 0.75 | 1.11 | 1.86     | 1.68      | 1.49      | 1.32       | 0.58           |
| MR-10                                               | S      | 16641 | 0.75  | 1.29 | 2.32 | 1.30     | 2.71      | 2.05      | 3.43       | 0.58           |
| FR-11R                                              | B      | 18453 | -0.25 | 0.46 | 0.94 | 0.77     | 1.16      | 0.53      | 0.60       | 0.41           |
| MR-12R                                              | S      | 12348 | -0.04 | 0.04 | 0.04 | 0.05     | 0.01      | 0.00      | 0.01       | 0.13           |
| SR-14                                               | B      | 15588 | 0.27  | 0.39 | 0.71 | 0.46     | 0.58      | 0.73      | 0.86       | 0.42           |
| USGS02198920<br>(Houlinan Bridge)                   | M      | 3601  | -0.04 | 0.04 | 0.05 | 0.05     | 0.01      | 0.00      | 0.01       | 0.07           |
| USGS02198840<br>(I-95)                              | M      | 3533  | -0.06 | 0.10 | 0.13 | 0.22     | 0.14      | 0.16      | 0.15       | 0.48           |
| USGS021989784<br>(Lucknow Canal)                    | M      | 3526  | 0.81  | 1.36 | 2.22 | 2.26     | 2.37      | 3.07      | 3.11       | 0.56           |
| USGS02198791<br>(US F&W Docks)                      | M      | 3601  | 0.13  | 0.24 | 0.41 | 0.32     | 0.34      | 0.45      | 0.52       | 0.44           |

\* S = Surface

B = Bottom

M = Mid-Depth

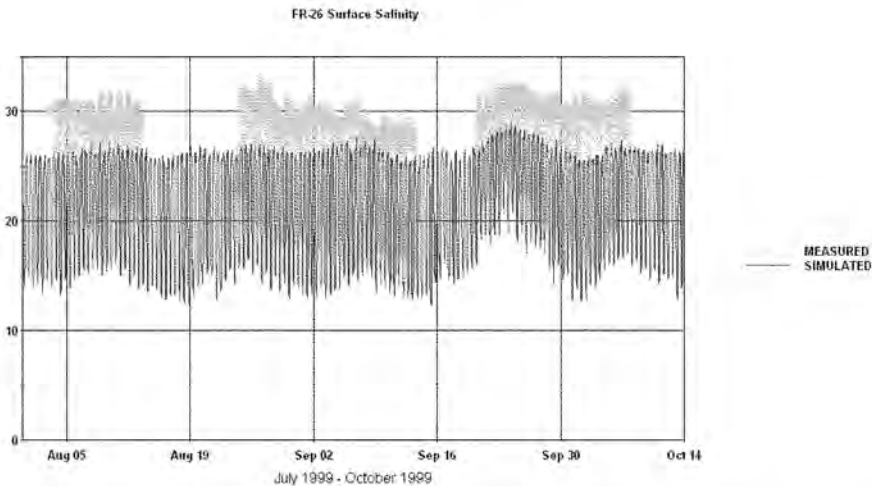


Figure J-1 Salinity (ppt) Calibration at FR-26 (Surface) for July 31, 1999 through October 13, 1999

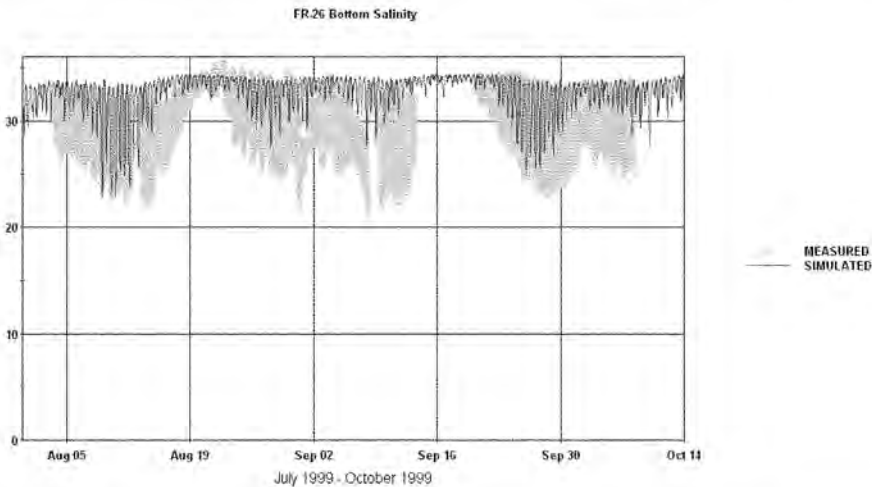


Figure J-2 Salinity (ppt) Calibration at FR-26 (Bottom) for July 31, 1999 through October 13, 1999

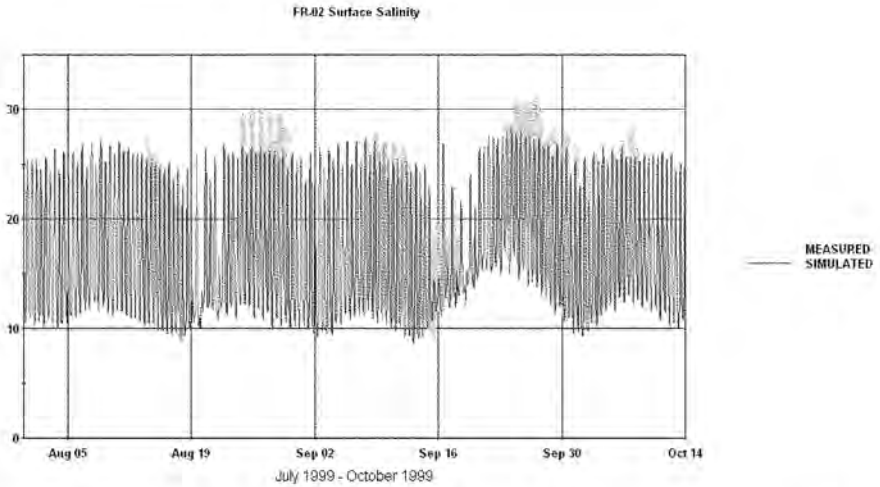


Figure J-3 Salinity (ppt) Calibration at FR-02 (Surface) for July 31, 1999 through October 13, 1999

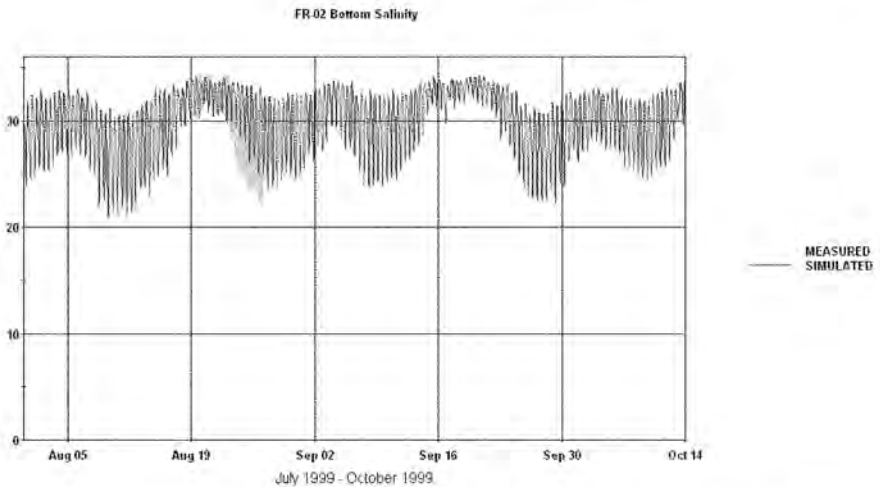


Figure J-4 Salinity (ppt) Calibration at FR-02 (Bottom) for July 31, 1999 through October 13, 1999

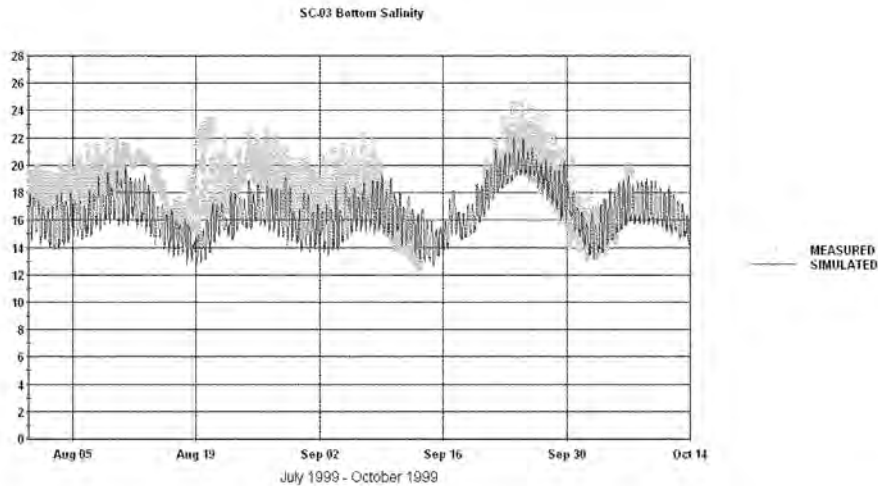


Figure J-5 Salinity (ppt) Calibration at SC-03 (Bottom) for July 31, 1999 through October 13, 1999

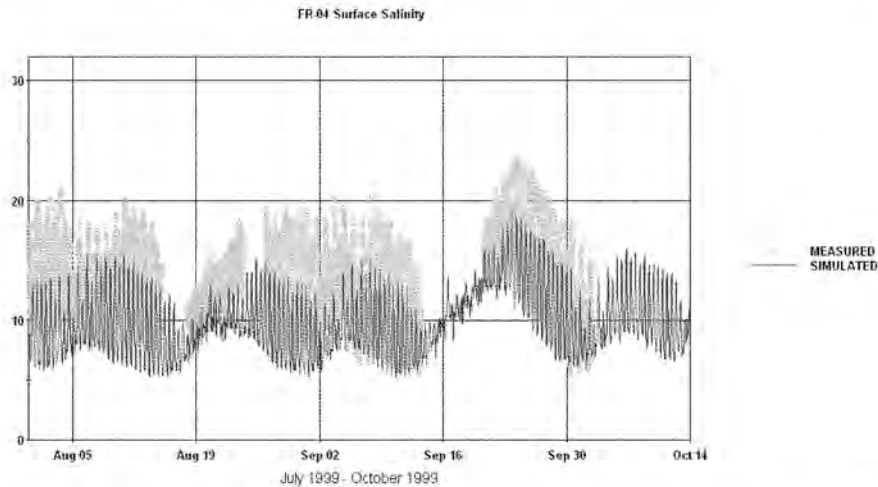


Figure J-6 Salinity (ppt) Calibration at FR-04 (Surface) for July 31, 1999 through October 13, 1999

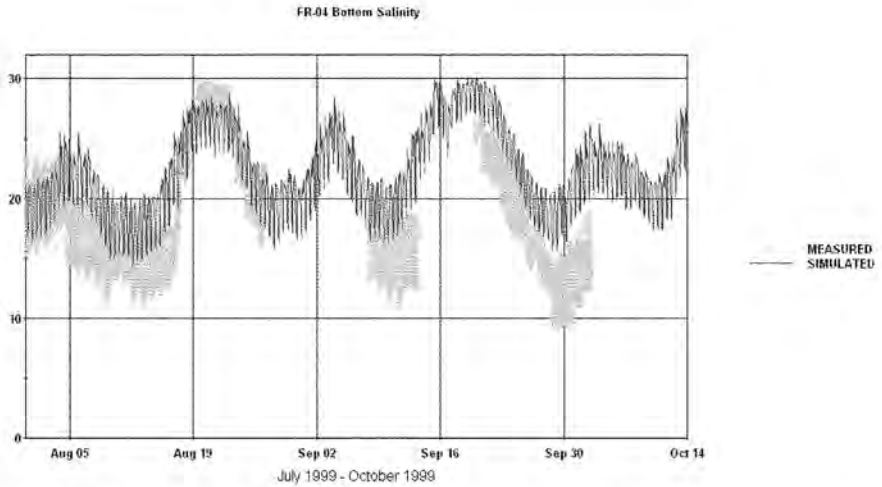


Figure J-7 Salinity (ppt) Calibration at FR-04 (Bottom) for July 31, 1999 through October 13, 1999

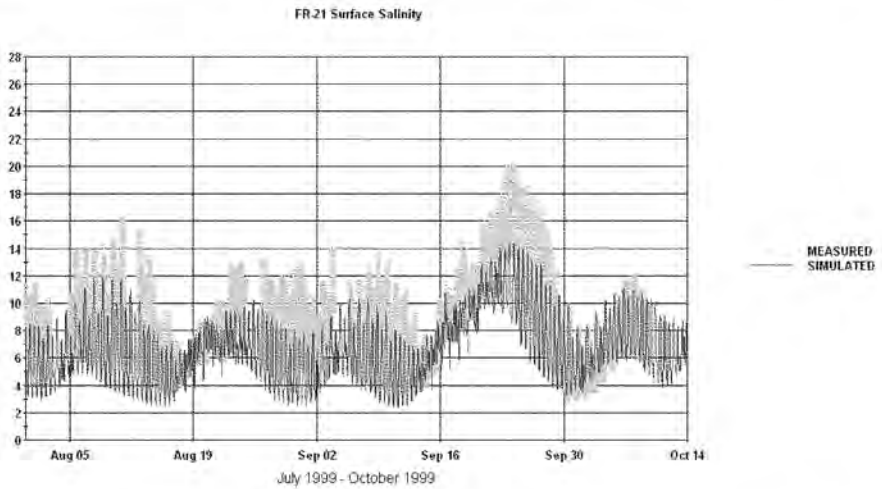


Figure J-8 Salinity (ppt) Calibration at FR-21 (Surface) for July 31, 1999 through October 13, 1999

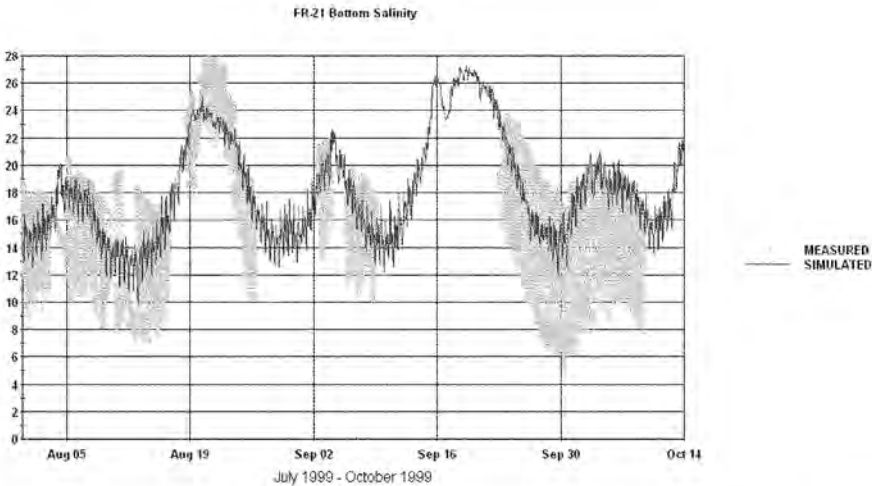


Figure J-9 Salinity (ppt) Calibration at FR-21 (Bottom) for July 31, 1999 through October 13, 1999

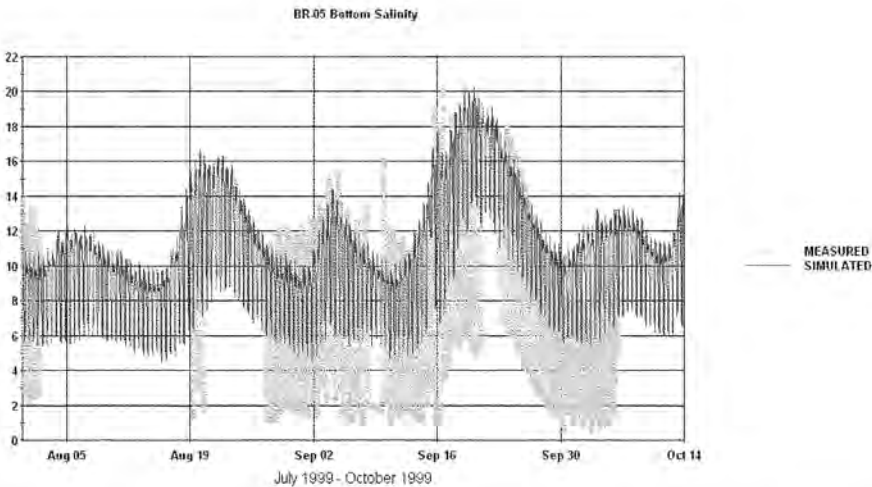


Figure J-10 Salinity (ppt) Calibration at BR-05 (Bottom) for July 31, 1999 through October 13, 1999

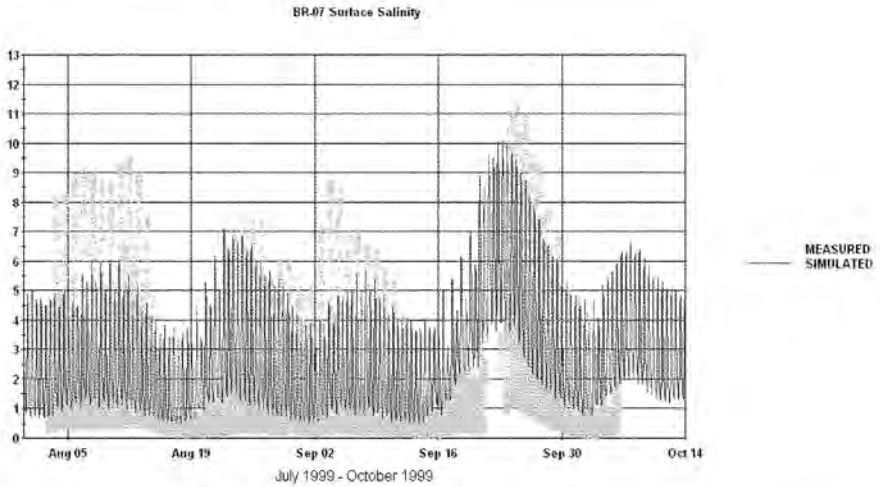


Figure J-11 Salinity (ppt) Calibration at BR-07 (Surface) for July 31, 1999 through October 13, 1999

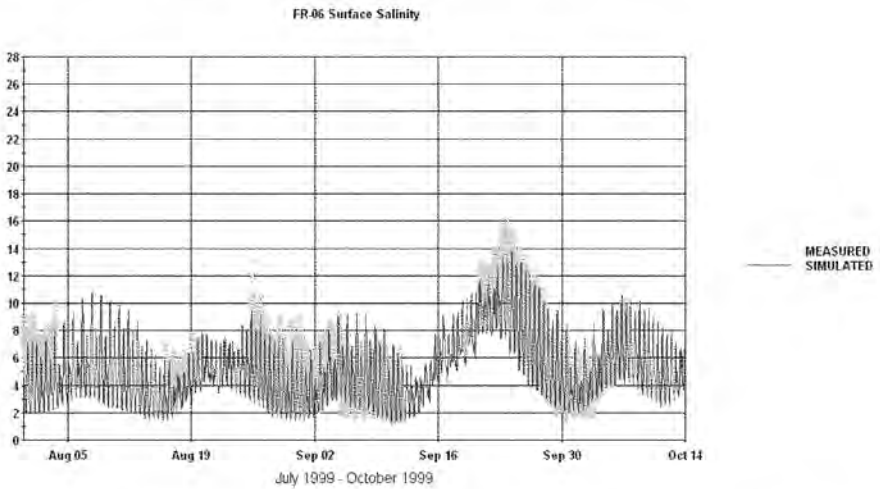


Figure J-12 Salinity (ppt) Calibration at FR-06 (Surface) for July 31, 1999 through October 13, 1999



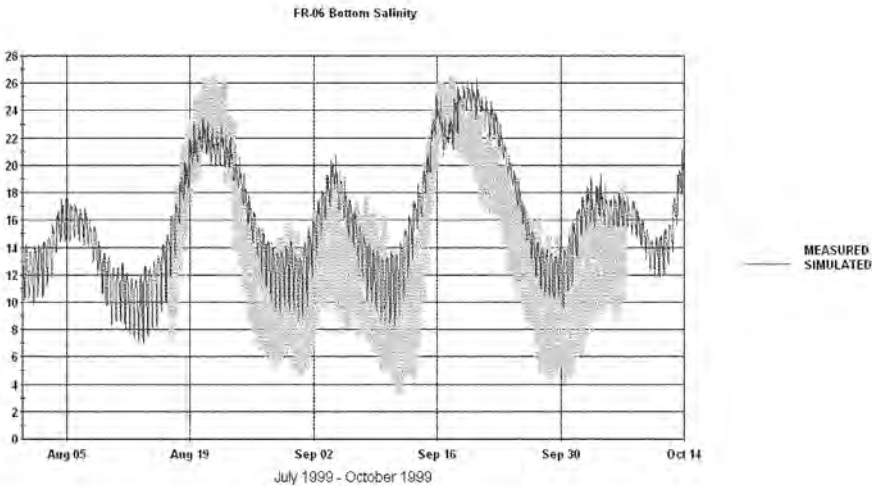


Figure J-13 Salinity (ppt) Calibration at FR-06 (Bottom) for July 31, 1999 through October 13, 1999

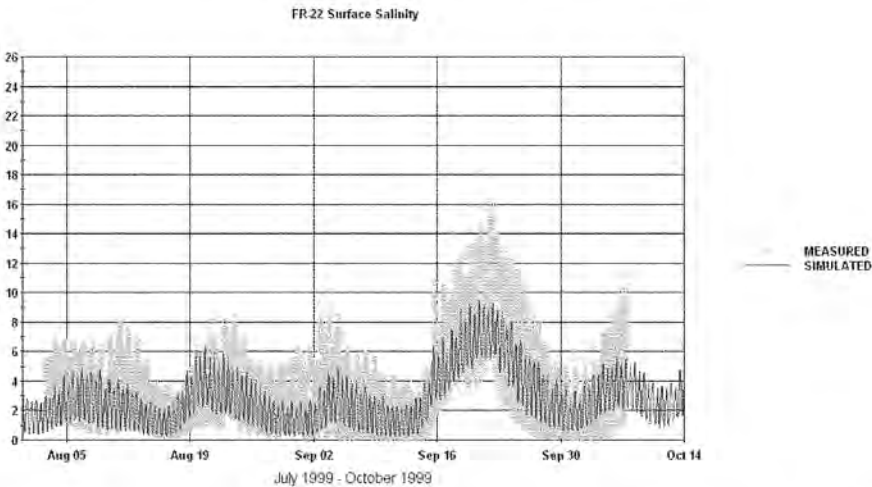


Figure J-14 Salinity (ppt) Calibration at FR-22 (Surface) for July 31, 1999 through October 13, 1999

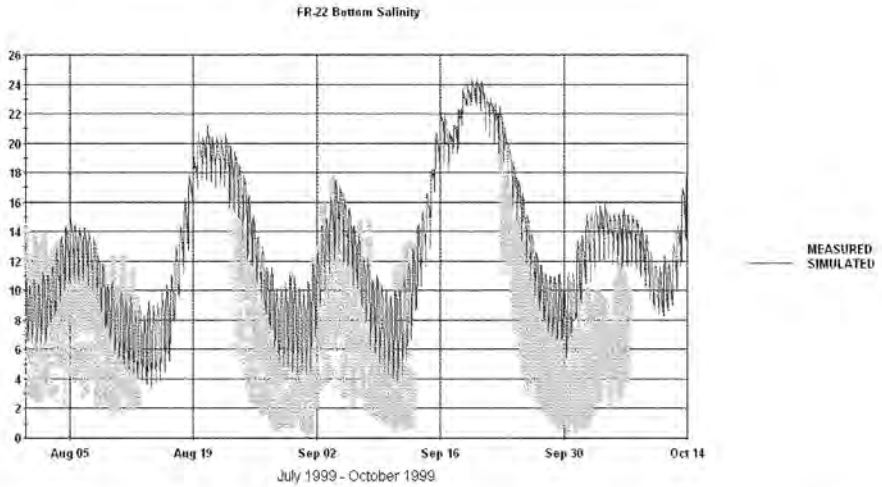


Figure J-15 Salinity (ppt) Calibration at FR-22 (Bottom) for July 31, 1999 through October 13, 1999

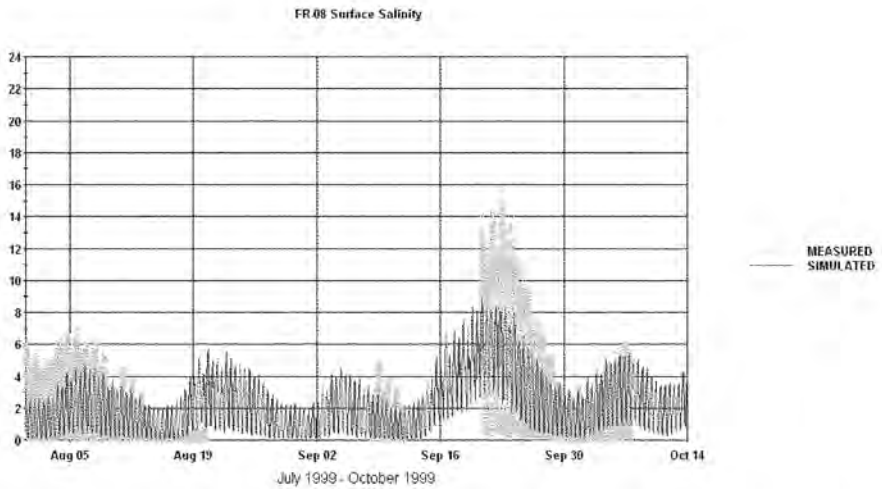


Figure J-16 Salinity (ppt) Calibration at FR-08 (Surface) for July 31, 1999 through October 13, 1999

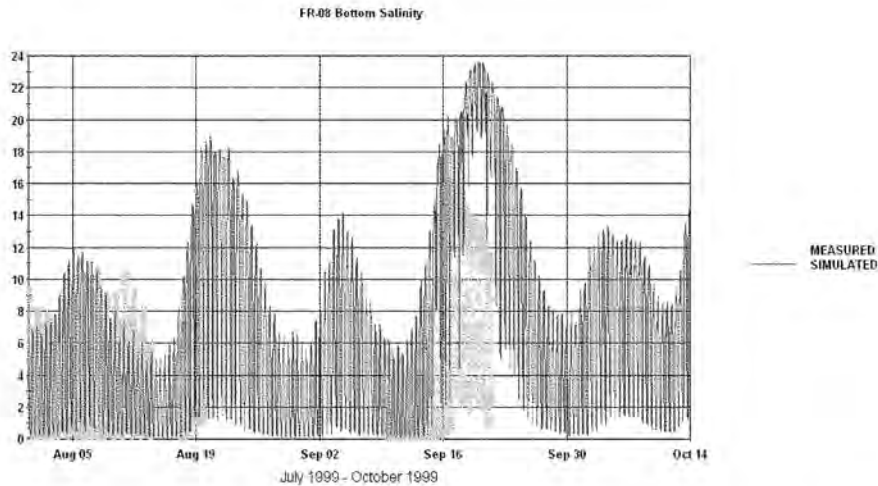


Figure J-17 Salinity (ppt) Calibration at FR-08 (Bottom) for July 31, 1999 through October 13, 1999

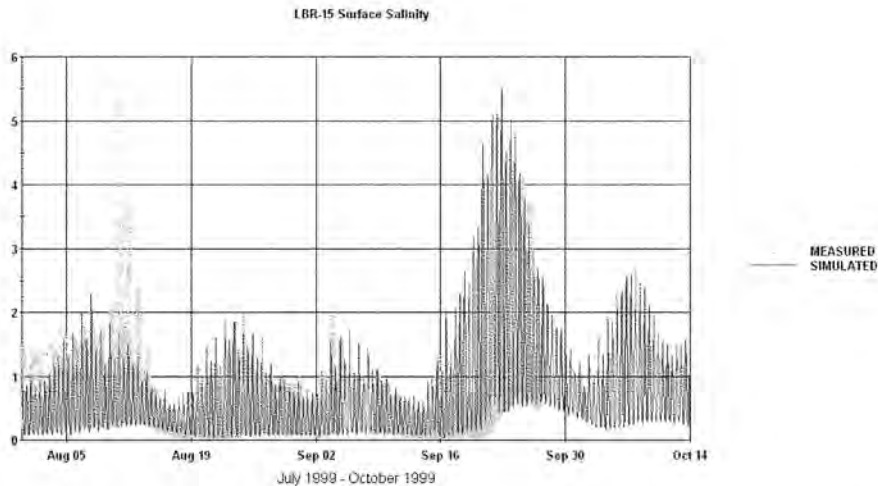


Figure J-18 Salinity (ppt) Calibration at LBR-15 (Surface) for July 31, 1999 through October 13, 1999

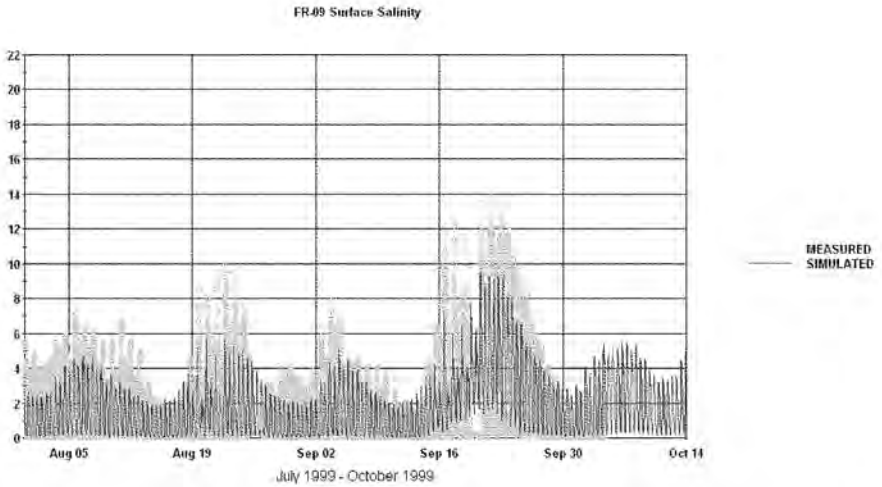


Figure J-19 Salinity (ppt) Calibration at FR-09 (Surface) for July 31, 1999 through October 13, 1999

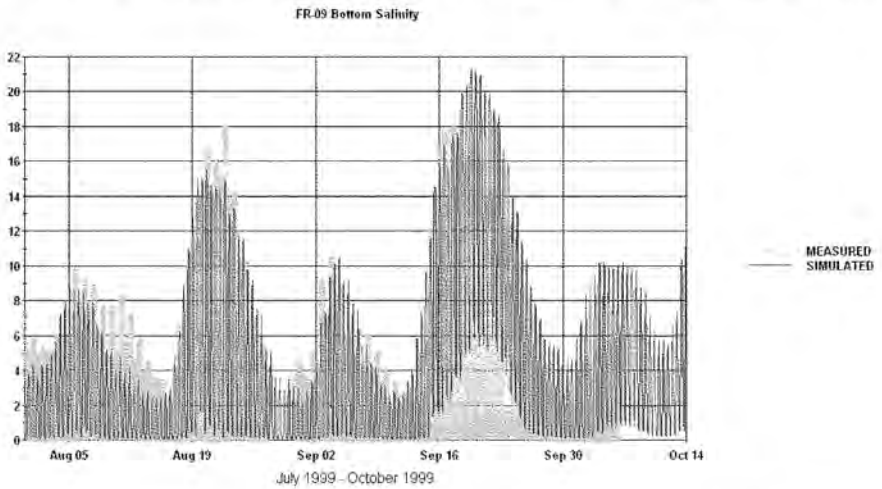


Figure J-20 Salinity (ppt) Calibration at FR-09 (Bottom) for July 31, 1999 through October 13, 1999

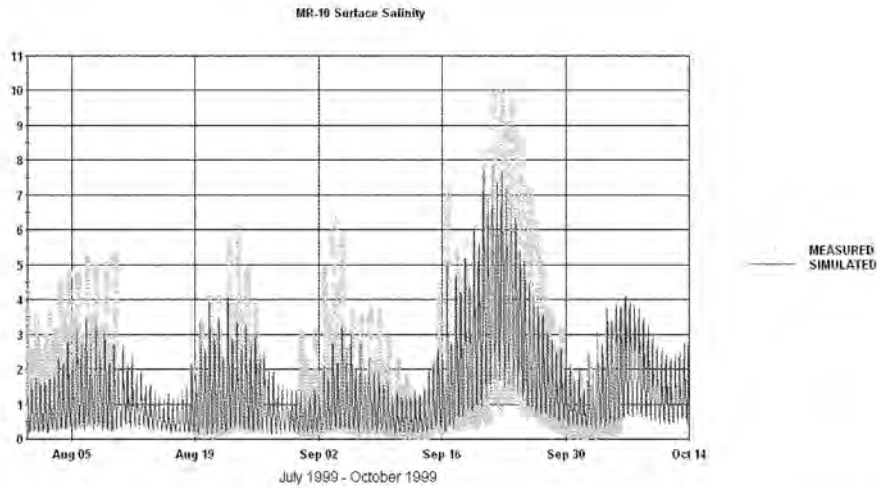


Figure J-21 Salinity (ppt) Calibration at MR-10 (Surface) for July 31, 1999 through October 13, 1999

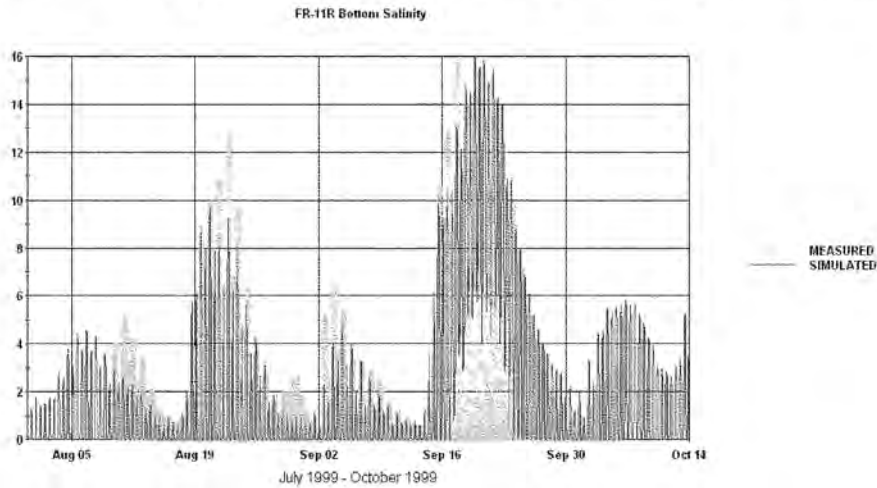


Figure J-22 Salinity (ppt) Calibration at FR-11R (Bottom) for July 31, 1999 through October 13, 1999

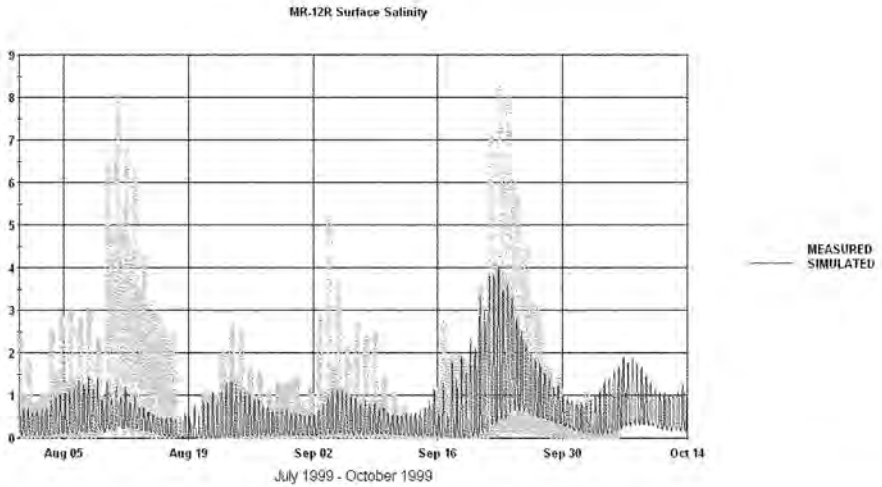


Figure J-23 Salinity (ppt) Calibration at MR-12R (Surface) for July 31, 1999 through October 13, 1999

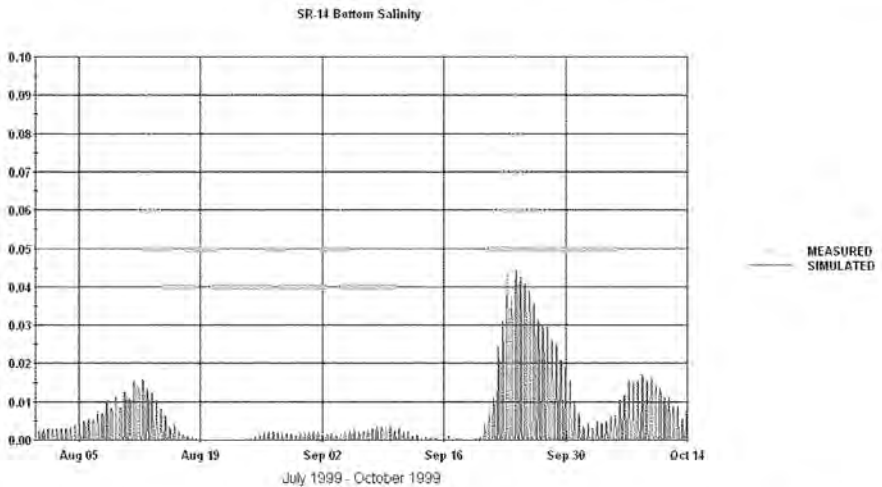


Figure J-24 Salinity (ppt) Calibration at SR-14 (Bottom) for July 31, 1999 through October 13, 1999

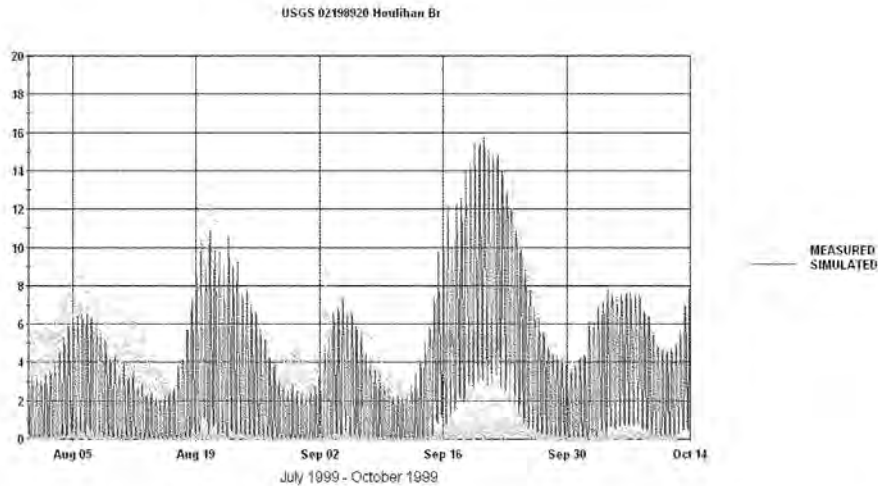


Figure J-25 Salinity (ppt) Calibration at Houlihan Bridge/Port Wentworth (Mid-depth) for July 31, 1999 through October 13, 1999

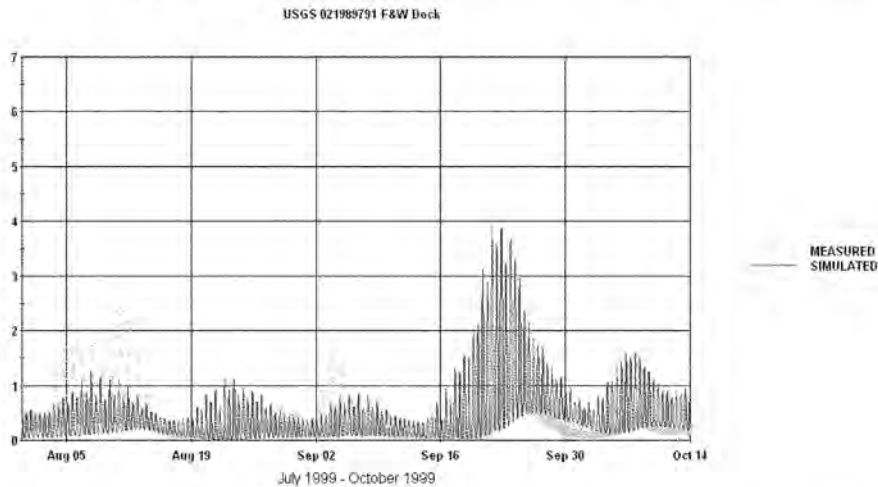


Figure J-26 Salinity (ppt) Calibration at US F&W Docks (Mid-depth) for July 31, 1999 through October 13, 1999

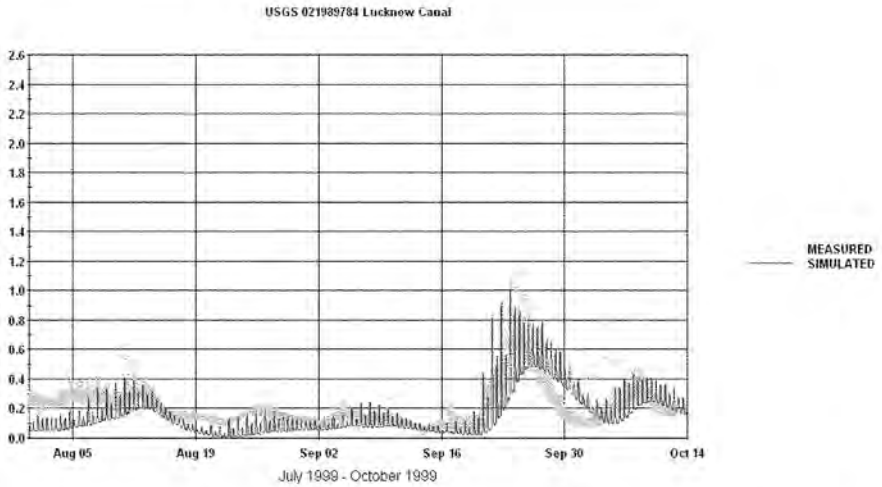


Figure J-27 Salinity (ppt) Calibration at Lucknow Canal (Mid-depth) for July 31, 1999 through October 13, 1999

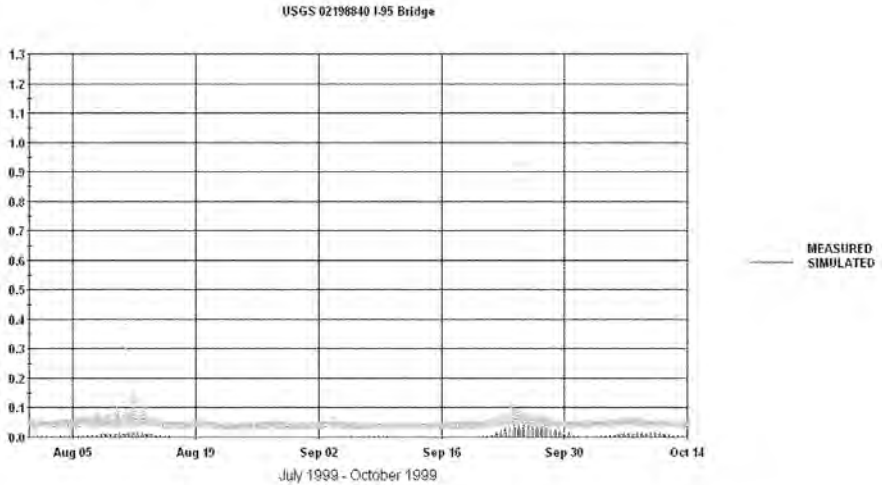


Figure J-28 Salinity (ppt) Calibration at I-95 Bridge (Mid-depth) for July 31, 1999 through October 13, 1999



**APPENDIX K    1997 SALINITY COMPARISONS**



Table K-1 Summary Percentiles for Salinity (ppt) for July 9, 1997 through October 6, 1997

| July 9 - October 6, 1997<br>(Julian Days 190-279) |        |           |      |      |          |      |      |            |      |      |                    |        |        |                                 |
|---------------------------------------------------|--------|-----------|------|------|----------|------|------|------------|------|------|--------------------|--------|--------|---------------------------------|
| Stations                                          | Depth* | Simulated |      |      | Measured |      |      | Difference |      |      | Percent Difference |        |        | Evaluation<br>Criteria<br>(ppt) |
|                                                   |        | 10%       | 50%  | 90%  | 10%      | 50%  | 90%  | 10%        | 50%  | 90%  | 10%                | 50%    | 90%    |                                 |
| FR-02                                             | S      | 9.2       | 13.2 | 24.5 | 10.2     | 18.0 | 21.6 | -1.0       | -4.8 | 2.7  | 10.1               | 10.2   | -12.4  | >5                              |
| FR-02                                             | B      | 25.2      | 30.5 | 35.0 | 18.8     | 25.4 | 29.1 | 5.4        | 5.1  | 3.9  | -29.1              | -20.0  | -13.5  | >5                              |
| SC-03                                             | B      | 13.1      | 15.7 | 18.2 | 11.2     | 14.4 | 18.3 | 1.9        | 1.3  | -0.1 | -17.4              | -9.2   | 0.6    | >5                              |
| FR-04                                             | S      | 5.3       | 8.6  | 12.3 | 5.1      | 9.2  | 14.7 | 0.2        | -0.6 | -2.4 | -5.4               | 6.2    | 18.3   | >5                              |
| FR-04                                             | B      | 15.9      | 22.2 | 26.6 | 12.8     | 18.6 | 23.3 | 3.1        | 3.6  | 3.3  | -24.4              | -19.3  | -14.3  | >5                              |
| FR-05                                             | B      | 6.0       | 8.9  | 13.0 | 1.0      | 5.4  | 10.3 | 5.0        | 4.5  | 3.6  | -48.0              | -57.9  | -35.2  | >5                              |
| FR-05                                             | S      | 1.2       | 3.6  | 6.6  | 1.4      | 3.9  | 7.0  | -0.2       | -3.3 | -0.4 | -11.1              | 6.5    | 6.0    | <5                              |
| FR-06                                             | B      | 6.4       | 16.2 | 20.8 | 2.2      | 10.5 | 17.4 | 3.6        | 5.7  | 3.4  | -127.8             | -54.1  | -10.3  | >5                              |
| BR-07                                             | B      | 0.4       | 2.9  | 6.9  | 0.1      | 0.4  | 3.3  | 0.3        | 2.6  | 3.6  | -320.9             | -696.5 | -109.5 | >5                              |
| FR-08                                             | S      | 0.1       | 1.4  | 4.3  | 0.1      | 0.4  | 5.3  | 0.0        | -1.0 | -1.0 | 15.3               | -233.5 | 18.0   | <5                              |
| FR-08                                             | B      | 0.1       | 3.7  | 14.7 | 0.1      | 1.2  | 10.0 | 0.0        | 2.5  | 4.7  | -23.8              | -209.3 | -47.3  | >5                              |
| FR-09                                             | B      | 0.0       | 1.4  | 9.8  | 0.0      | 0.3  | 6.3  | 0.0        | 1.1  | 4.8  | 0.0                | -381.7 | -34.4  | <5                              |
| MR-10                                             | B      | 0.2       | 0.7  | 2.8  | 0.1      | 0.5  | 2.9  | 0.1        | 0.2  | -0.1 | -54.9              | -38.1  | 3.4    | <5                              |
| FR-11                                             | B      | 0.0       | 0.0  | 0.1  | 0.0      | 0.0  | 0.2  | 0.0        | 0.0  | -0.1 | 0.0                | 0.0    | 31.5   | <5                              |
| MR-12                                             | B      | 0.0       | 0.1  | 0.6  | 0.0      | 0.1  | 0.9  | 0.0        | 0.0  | -0.3 | 0.0                | 26.9   | 35.5   | <5                              |
| 1BR-13                                            | B      | 0.0       | 0.0  | 0.1  | 0.0      | 0.1  | 0.2  | 0.0        | -0.1 | -0.1 | 0.0                | 83.8   | 63.0   | <5                              |
| USGS02198920<br>(Houlman Bridge)                  | M      | 0.0       | 1.3  | 6.8  | 0.0      | 0.3  | 5.4  | 0.0        | 1.1  | 1.4  | 0.6                | -421.6 | -26.1  | <5                              |
| USGS02198791<br>(US F&W Docks)                    | M      | 0.0       | 0.1  | 0.7  | 0.0      | 0.1  | 0.3  | 0.0        | 0.1  | 0.4  | 65.3               | -91.1  | -155.4 | <5                              |
| USGS021989784<br>(Lucknow Canal)                  | M      | 0.0       | 0.0  | 0.2  | 0.0      | 0.1  | 0.2  | 0.0        | 0.0  | 0.0  | 82.6               | 44.0   | -6.6   | <5                              |
| USGS02198840<br>(I-95)                            | M      | 0.0       | 0.0  | 0.0  | 0.0      | 0.0  | 0.0  | 0.0        | 0.0  | 0.0  | 100.0              | 100.0  | 97.8   | <5                              |

\* S = Surface  
B = Bottom  
M = Mid-Depth

Statistic Applicable for Criteria  
Meets Criteria

Table K-2 Summary Statistics for Salinity (ppt) for July 9, 1997 through October 6, 1997

| July 9 - October 6, 1997<br>(Julian Days 190-278) |        |       |       |      |      |          |           |           |            |                |
|---------------------------------------------------|--------|-------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Station                                           | Depth* | N     | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-02                                             | S      | 18002 | -0.29 | 2.33 | 2.80 | 15.31    | 5.62      | 15.60     | 4.35       | 0.74           |
| FR-02                                             | B      | 17704 | 4.85  | 4.86 | 5.34 | 29.78    | 3.17      | 24.93     | 3.37       | 0.59           |
| SC-03                                             | S      | 18022 | 1.13  | 2.30 | 2.83 | 15.71    | 1.92      | 14.58     | 2.81       | 0.20           |
| FR-04                                             | S      | 17955 | -0.94 | 1.77 | 2.26 | 8.71     | 2.76      | 9.64      | 3.62       | 0.68           |
| FR-04                                             | B      | 14858 | 3.32  | 3.43 | 4.11 | 21.64    | 4.03      | 18.32     | 3.99       | 0.67           |
| BR-05                                             | S      | 15485 | 4.32  | 4.46 | 5.00 | 9.86     | 3.03      | 5.54      | 3.46       | 0.50           |
| FR-06                                             | B      | 20134 | -0.26 | 1.06 | 1.43 | 3.84     | 2.02      | 4.10      | 2.16       | 0.60           |
| FR-06                                             | S      | 18097 | -4.36 | 4.51 | 5.37 | 14.72    | 5.40      | 10.37     | 5.27       | 0.68           |
| BR-07                                             | B      | 21437 | 2.26  | 1.97 | 2.60 | 2.38     | 1.14      | 1.82      | 0.30       | 0.11           |
| FR-08                                             | B      | 21744 | 0.18  | 0.85 | 1.27 | 1.83     | 1.65      | 1.65      | 2.37       | 0.75           |
| FR-08                                             | S      | 21030 | 2.54  | 2.67 | 3.94 | 5.76     | 5.63      | 3.72      | 3.88       | 0.74           |
| FR-09                                             | B      | 19866 | 1.67  | 1.73 | 2.74 | -3.29    | 4.13      | 1.62      | 2.58       | 0.79           |
| MR-10                                             | B      | 17767 | 0.07  | 0.46 | 0.70 | 1.14     | 1.22      | 1.07      | 1.42       | 0.76           |
| FR-11                                             | B      | 13321 | -0.03 | 0.10 | 0.31 | 0.10     | 0.38      | 0.13      | 0.43       | 0.52           |
| MR-12                                             | B      | 22750 | -0.11 | 0.17 | 0.35 | 0.21     | 0.32      | 0.32      | 0.54       | 0.68           |
| 1BR-13                                            | B      | 16083 | -0.08 | 0.09 | 0.20 | 0.04     | 0.07      | 0.12      | 0.22       | 0.39           |
| USGS02198920<br>(Houlman Bridge)                  | M      | 4273  | 0.78  | 1.00 | 1.55 | 2.47     | 2.83      | 1.89      | 2.60       | 0.78           |
| USGS02198791<br>(US F&W Docks)                    | M      | 4273  | 0.15  | 0.18 | 0.33 | 0.29     | 0.39      | 0.14      | 0.20       | 0.44           |
| USGS021989784<br>(Lucknow Canal)                  | M      | 4140  | -0.03 | 0.06 | 0.09 | 0.08     | 0.11      | 0.11      | 0.11       | 0.50           |
| USGS02198840<br>(I-95)                            | M      | 4273  | -0.04 | 0.04 | 0.04 | 0.00     | 0.00      | 0.04      | 0.01       | 0.15           |

\* S = Surface  
B = Bottom  
M = Mid-Depth

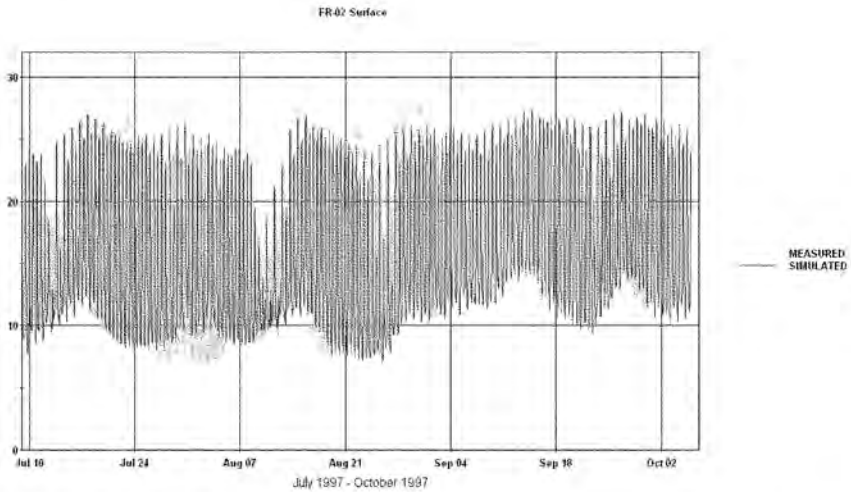


Figure K-1 Salinity (ppt) Calibration at FR-02 (Surface) for July 9, 1997 through October 6, 1997

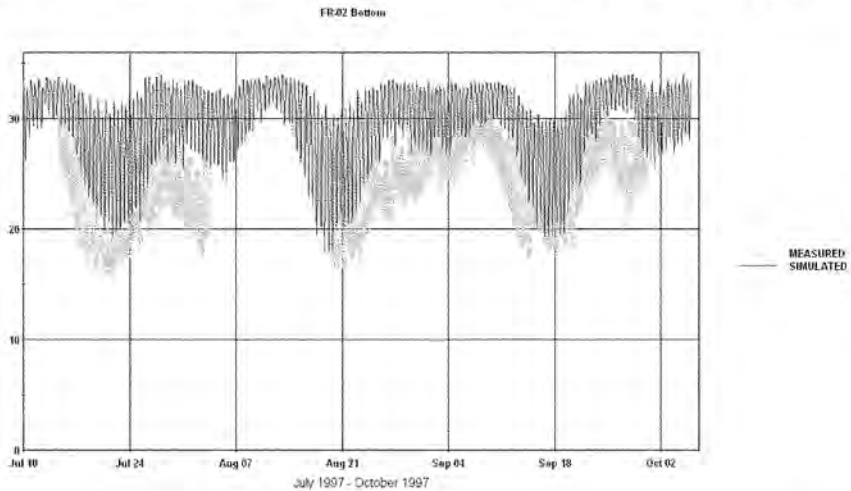


Figure K-2 Salinity (ppt) Calibration at FR-02 (Bottom) for July 9, 1997 through October 6, 1997

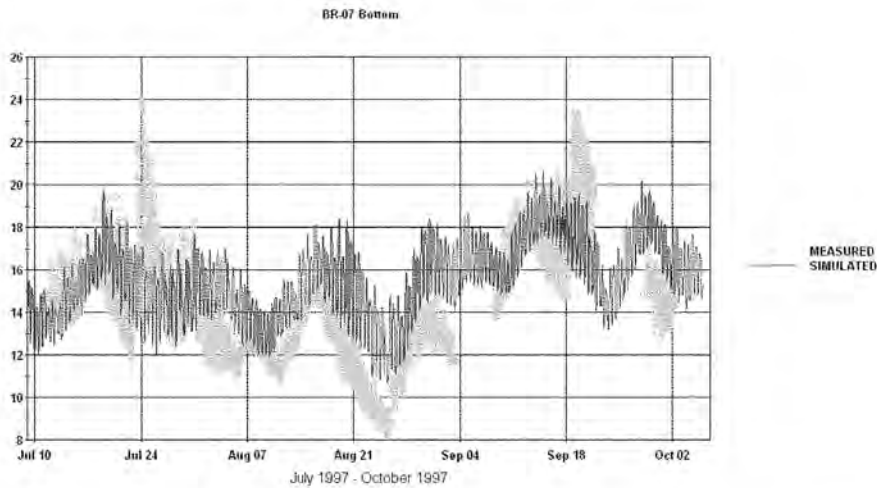


Figure K-3 Salinity (ppt) Calibration at SC-03 (Bottom) for July 9, 1997 through October 6, 1997

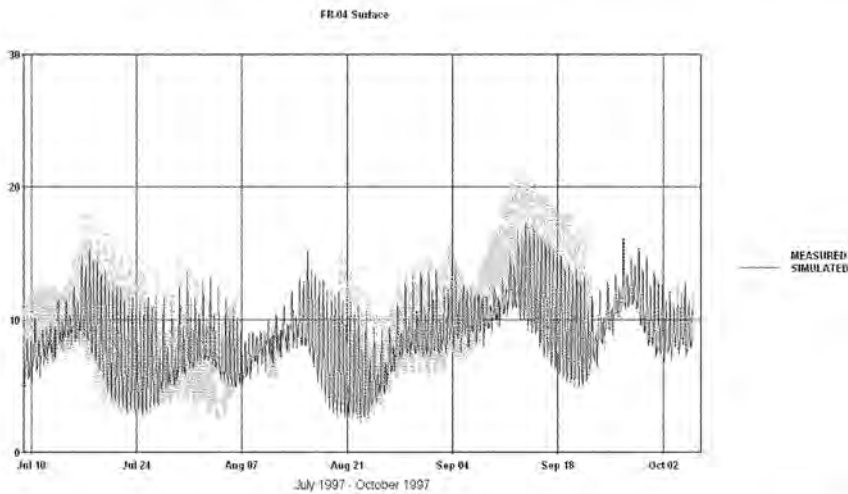


Figure K-4 Salinity (ppt) Calibration at FR-04 (Surface) for July 9, 1997 through October 6, 1997

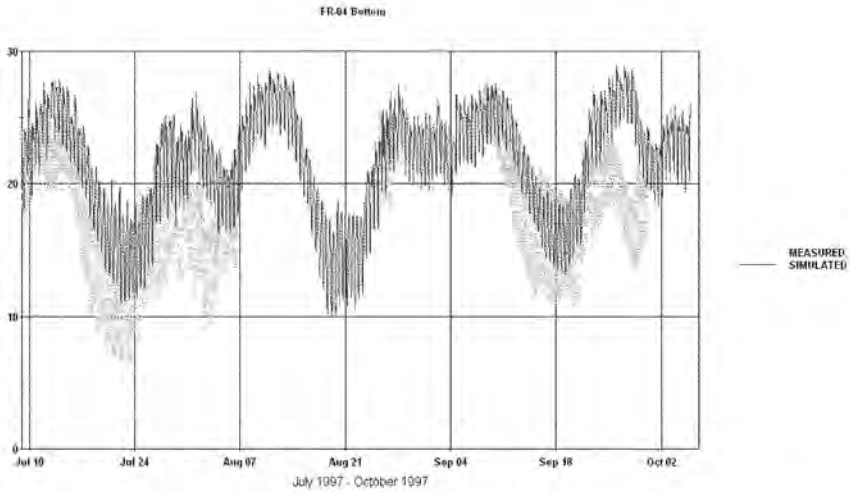


Figure K-5 Salinity (ppt) Calibration at FR-04 (Bottom) for July 9, 1997 through October 6, 1997

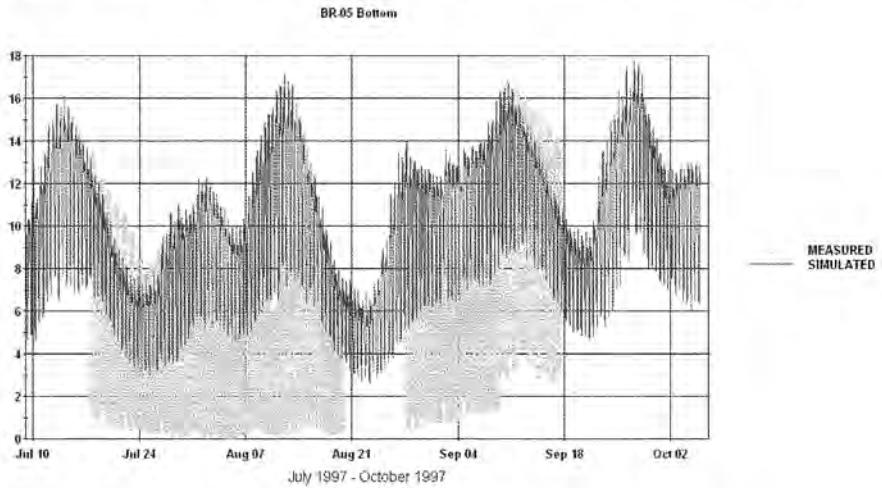


Figure K-6 Salinity (ppt) Calibration at BR-05 (Bottom) for July 9, 1997 through October 6, 1997

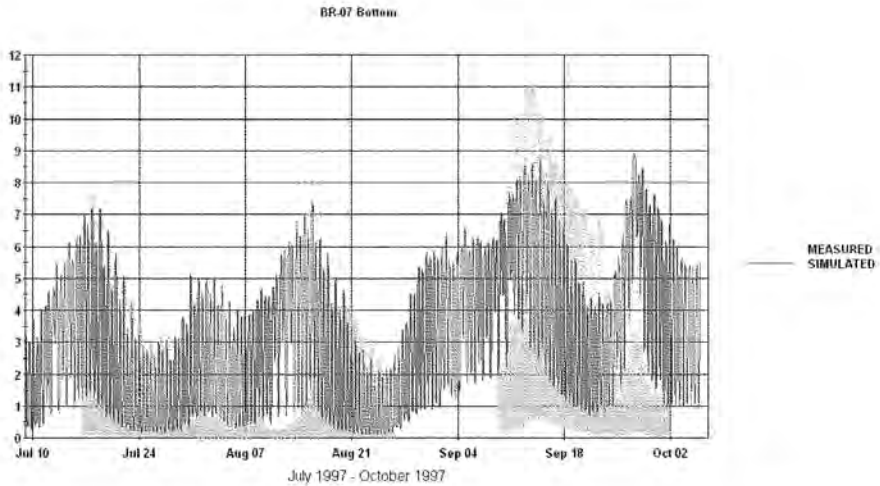


Figure K-7 Salinity (ppt) Calibration at BR-07 (Bottom) for July 9, 1997 through October 6, 1997

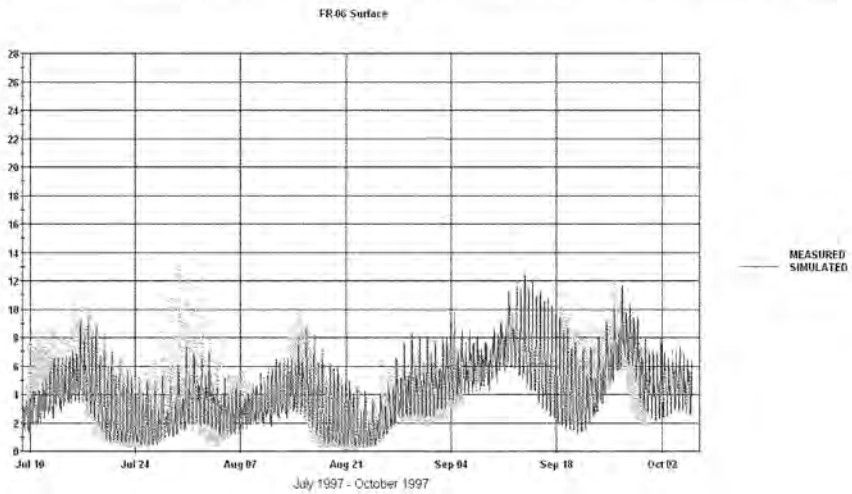


Figure K-8 Salinity (ppt) Calibration at FR-06 (Surface) for July 9, 1997 through October 6, 1997

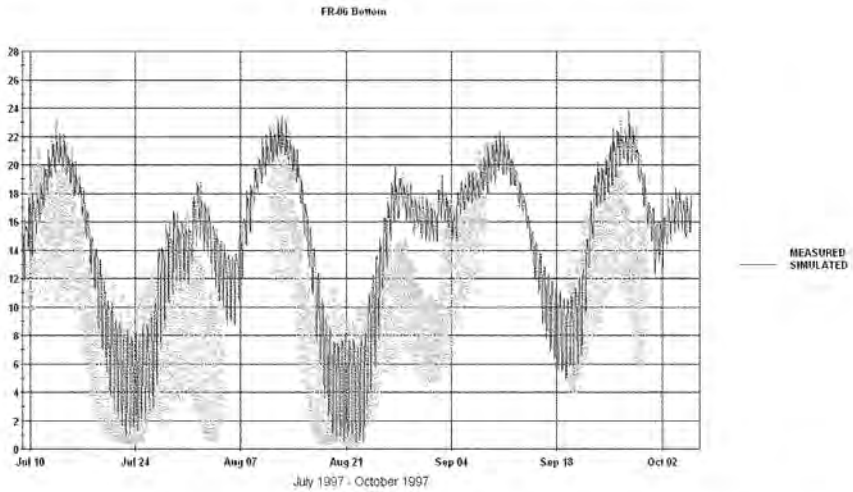


Figure K-9 Salinity (ppt) Calibration at FR-06 (Bottom) for July 9, 1997 through October 6, 1997

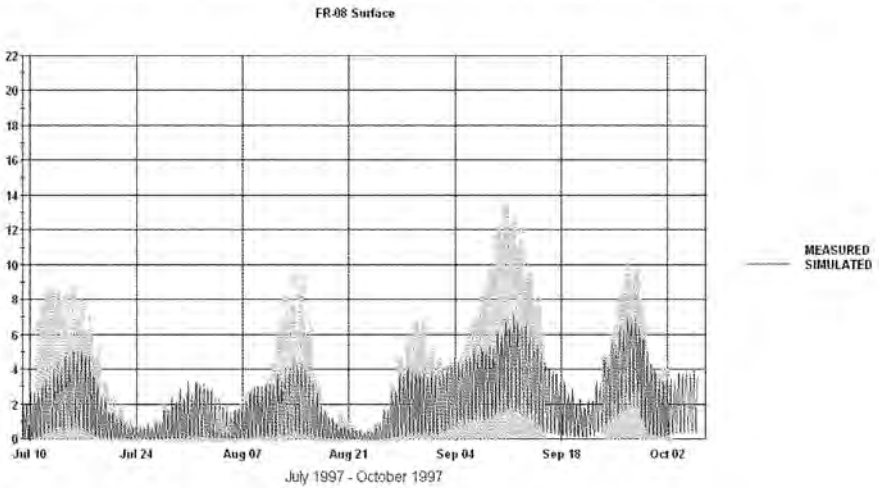


Figure K-10 Salinity (ppt) Calibration at FR-08 (Surface) for July 9, 1997 through October 6, 1997



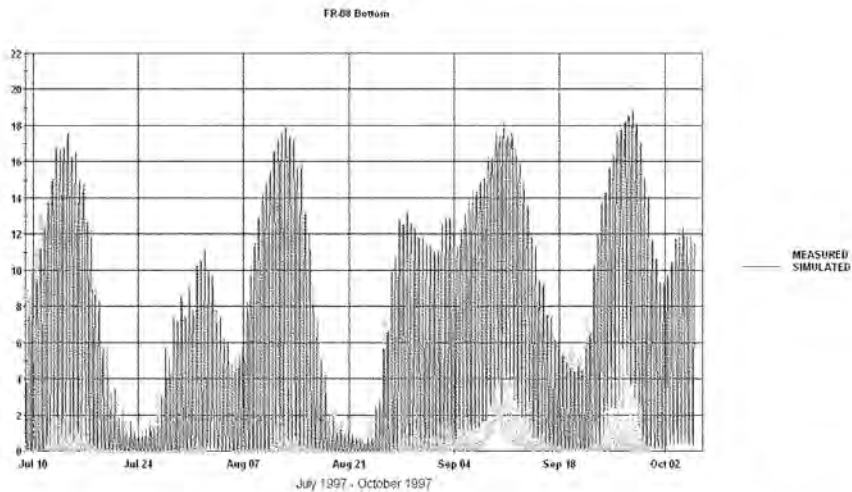


Figure K-11 Salinity (ppt) Calibration at FR-08 (Bottom) for July 9, 1997 through October 6, 1997

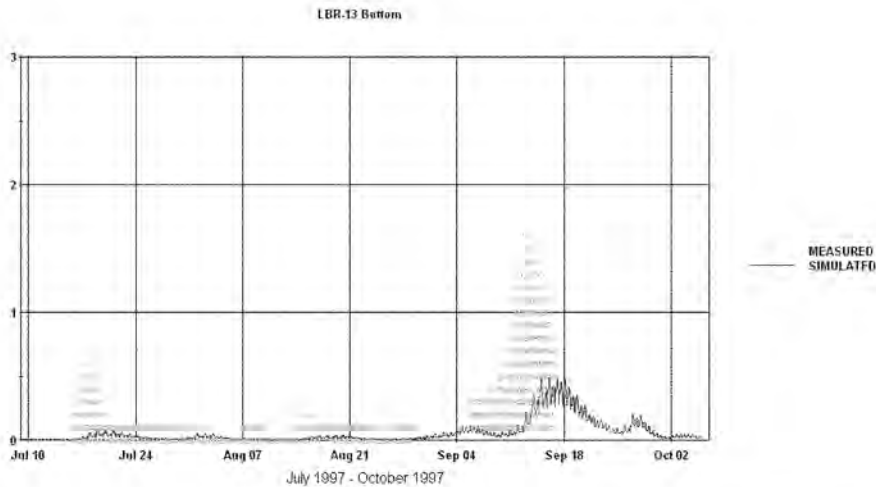


Figure K-12 Salinity (ppt) Calibration at LBR-13 (Bottom) for July 9, 1997 through October 6, 1997

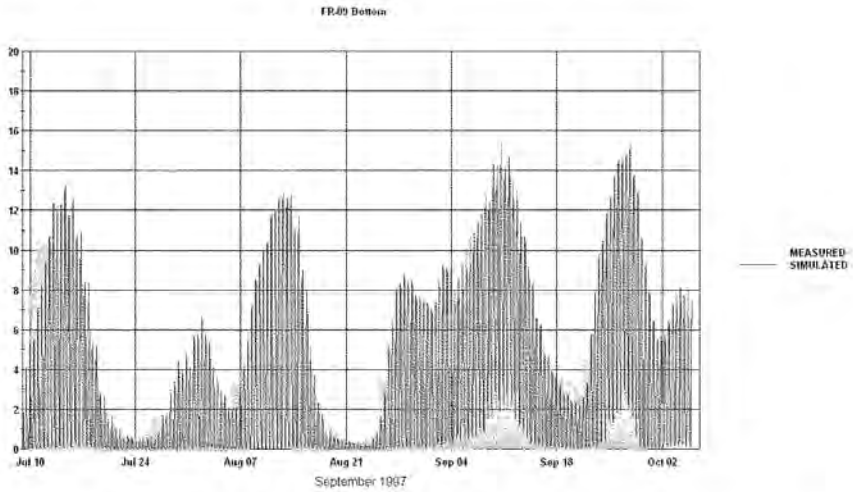


Figure K-13 Salinity (ppt) Calibration at FR-09 (Bottom) for July 9, 1997 through October 6, 1997

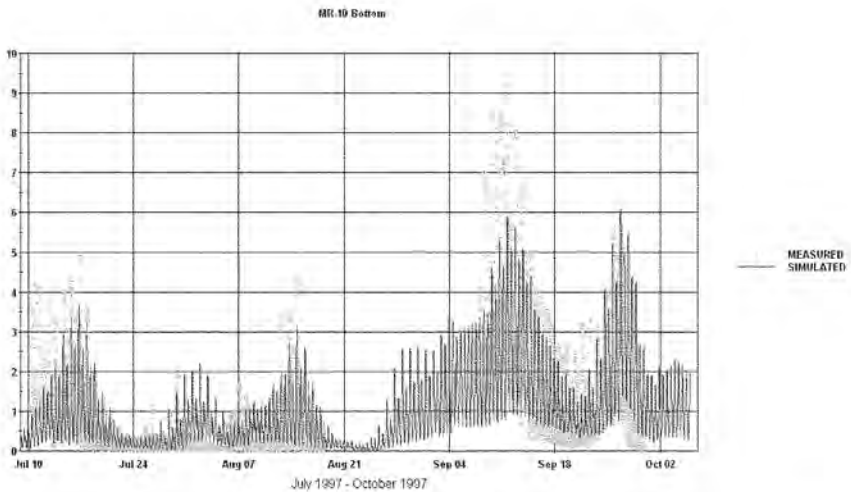


Figure K-14 Salinity (ppt) Calibration at MR-10 (Bottom) for July 9, 1997 through October 6, 1997

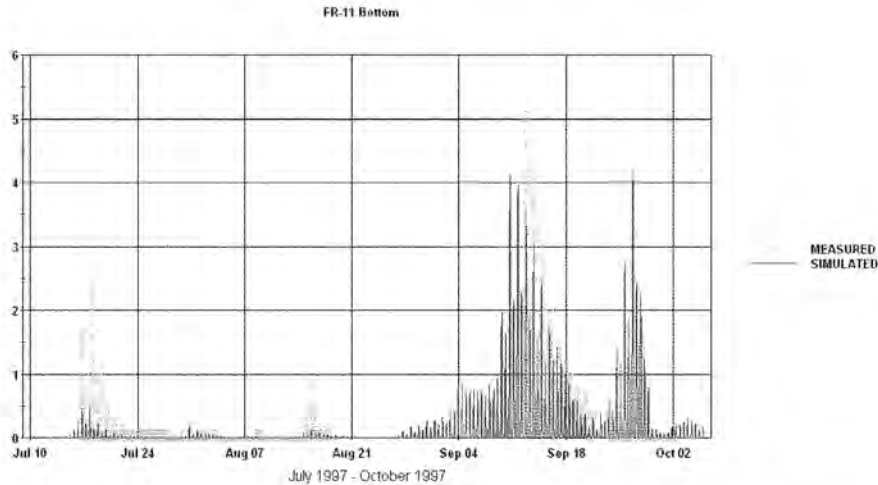


Figure K-15 Salinity (ppt) Calibration at FR-11 (Bottom) for July 9, 1997 through October 6, 1997

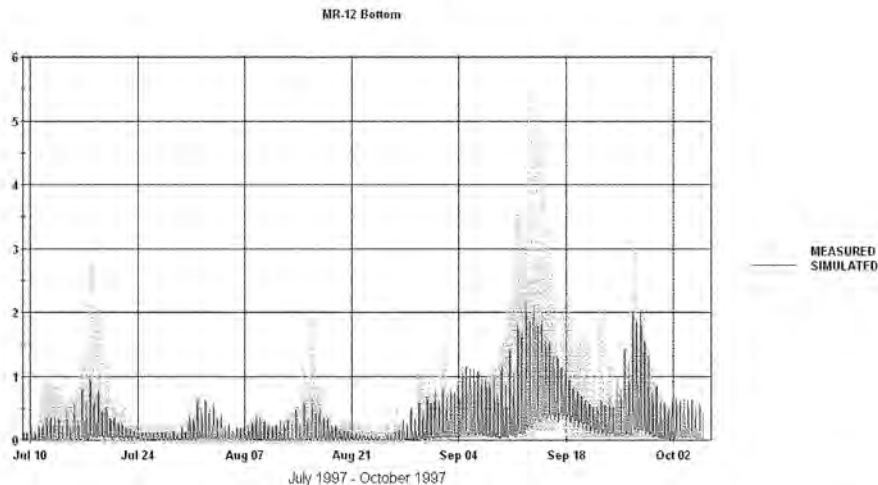


Figure K-16 Salinity (ppt) Calibration at MR-12 (Bottom) for July 9, 1997 through October 6, 1997

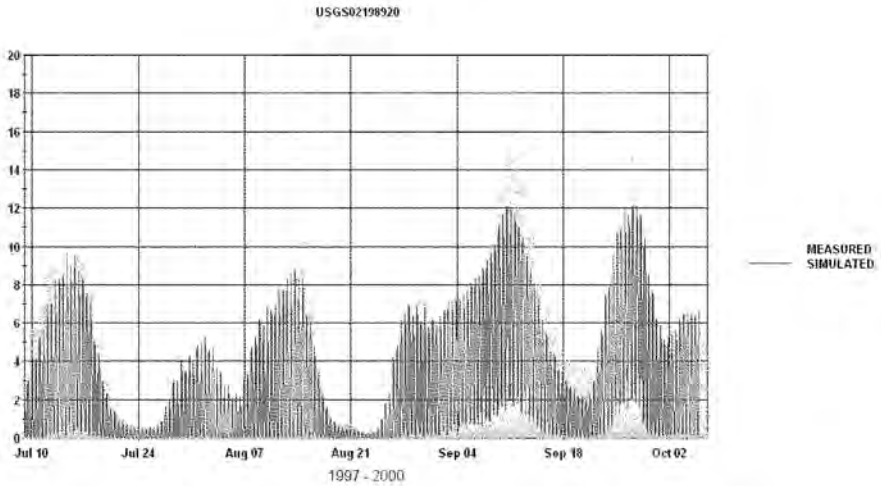


Figure K-17 Salinity (ppt) Calibration at Houlihan Bridge/Port Wentworth (Mid-depth) for July 9, 1997 through October 6, 1997

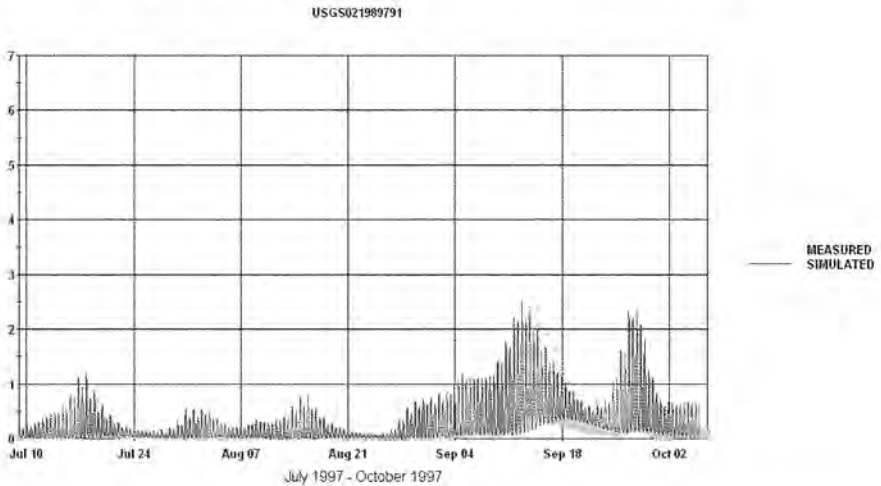


Figure K-18 Salinity (ppt) Calibration at US F&W Docks (Mid-depth) for July 9, 1997 through October 6, 1997

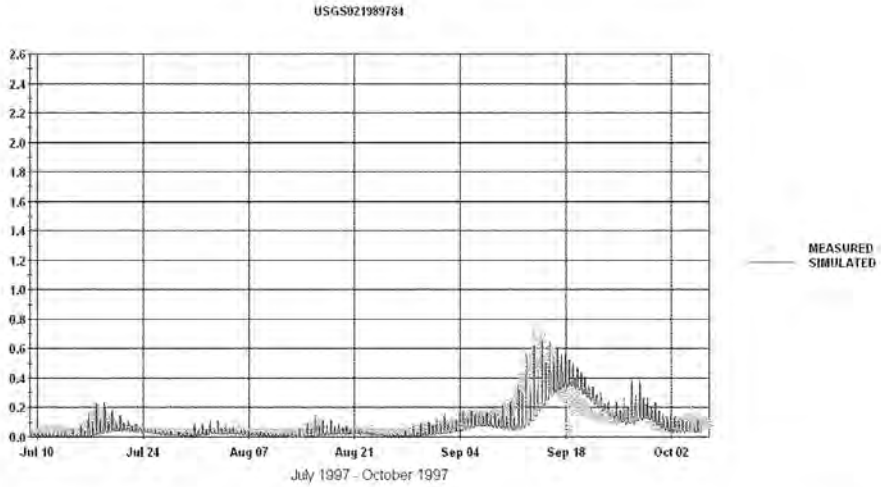


Figure K-19 Salinity (ppt) Calibration at Lucknow Canal (Mid-depth) for July 9, 1997 through October 6, 1997

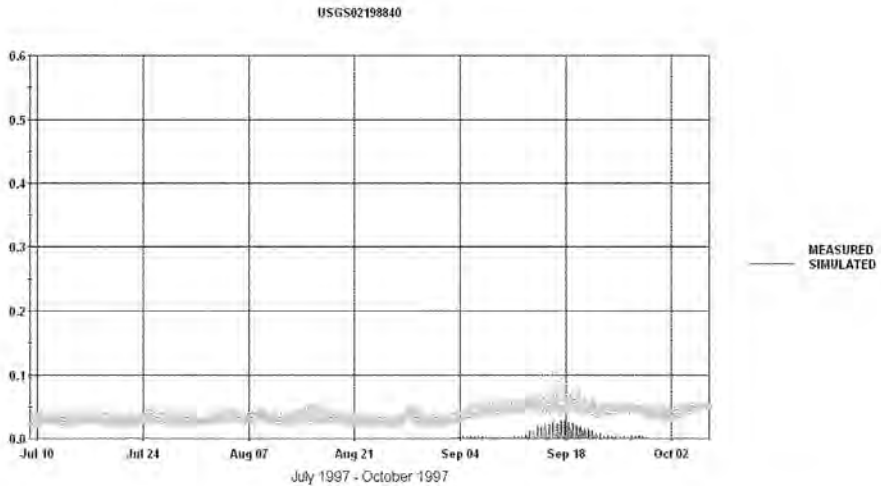


Figure K-20 Salinity (ppt) Calibration at I-95 Bridge (Mid-depth) for July 9, 1997 through October 6, 1997



**APPENDIX L 7-YEAR WATER SURFACE COMPARISONS**





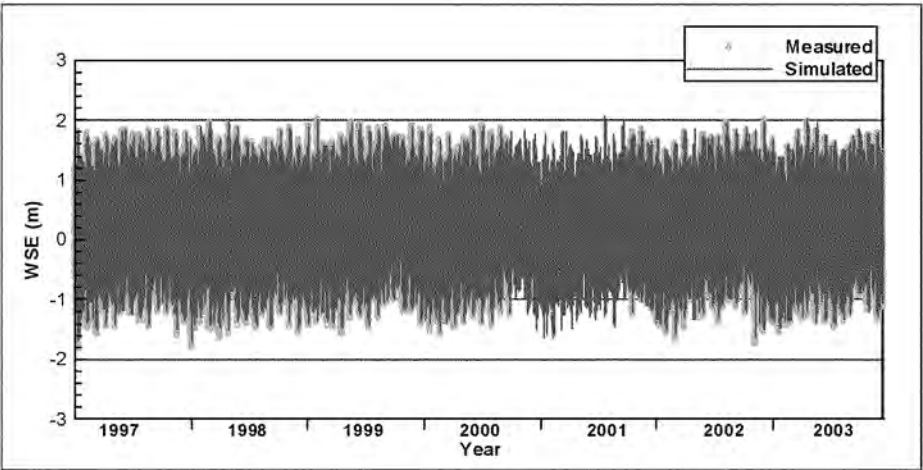


Figure L-1 7-Year Water Surface Comparison at USGS 02198980 Ft. Pulaski

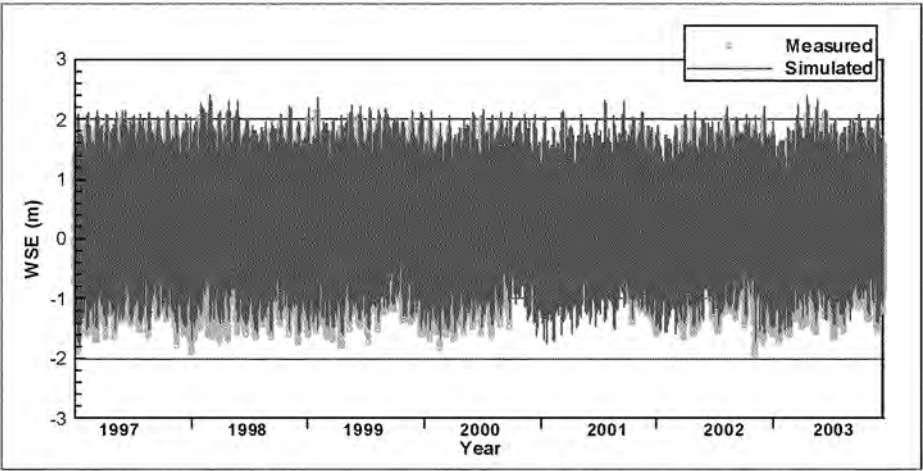


Figure L-2 7-Year Water Surface Comparison at USGS 02198977 Broad St.

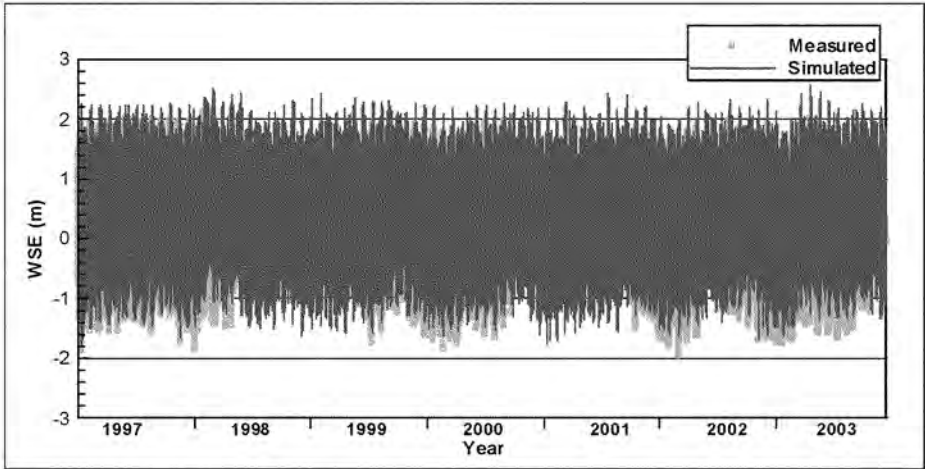


Figure L-3 7-Year Water Surface Comparison at USGS 02198920 Houlihan Bridge

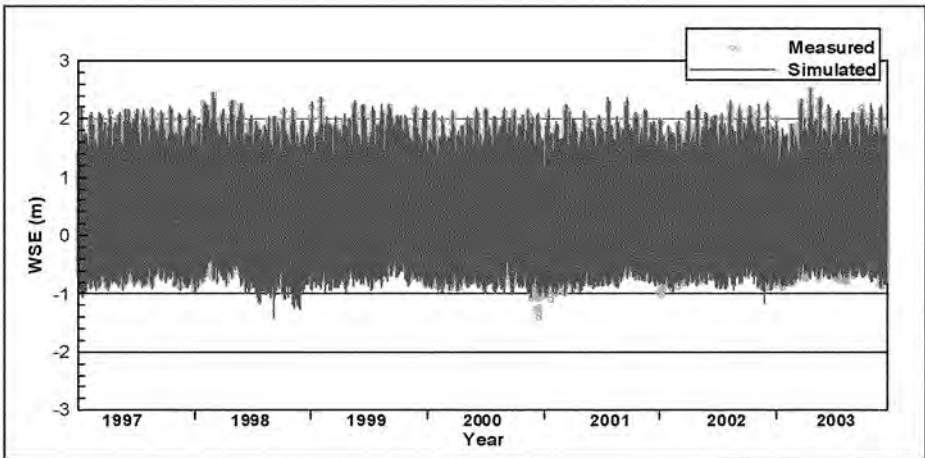


Figure L-4 7-Year Water Surface Comparison at USGS 02198979 Limehouse Creek

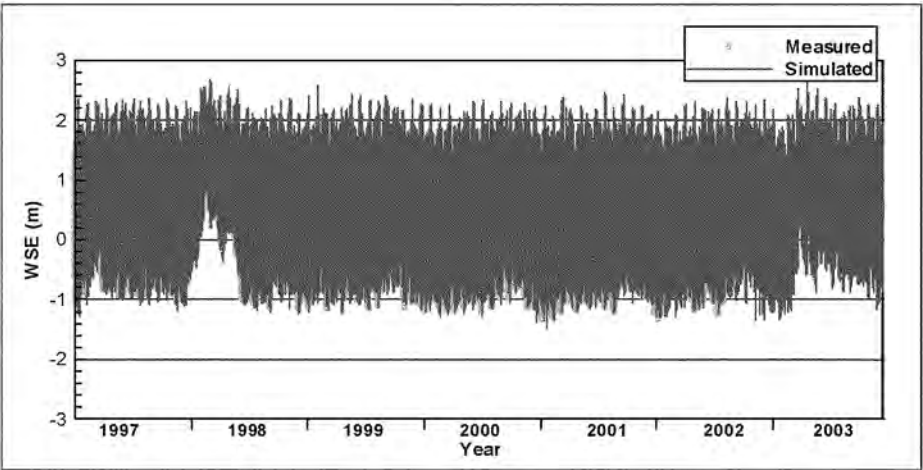


Figure L-5 7-Year Water Surface Comparison at USGS 02198840 I-95 Bridge



**APPENDIX M 7-YEAR SALINITY COMPARISONS**



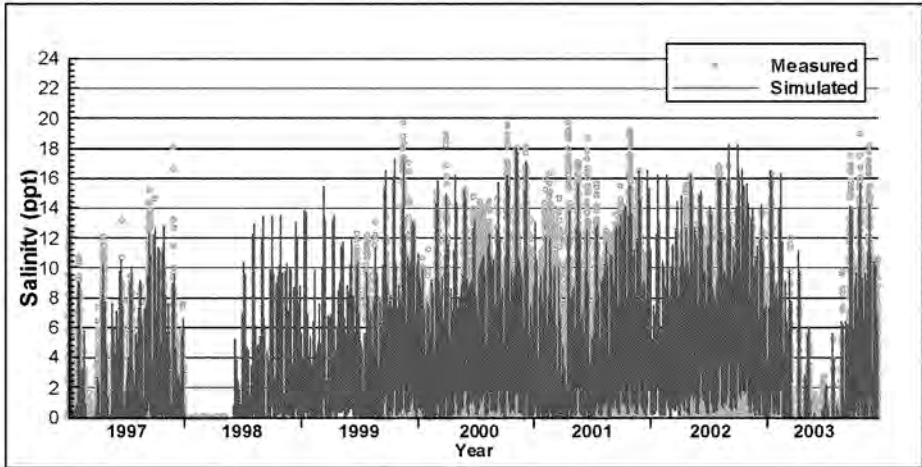


Figure M-1 7-Year Salinity Comparison at USGS 02198920 Houlihan Bridge (mid-depth)

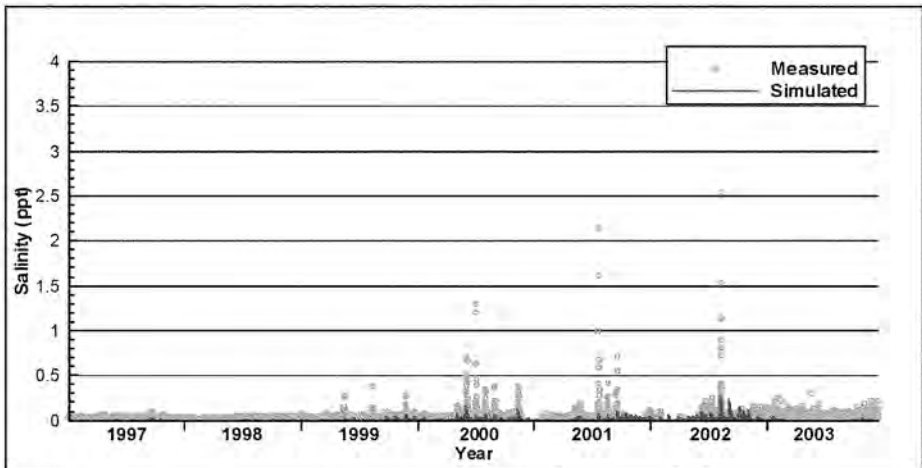


Figure M-2 7-Year Salinity Comparison at USGS 02198840 I-95 Bridge (mid-depth)

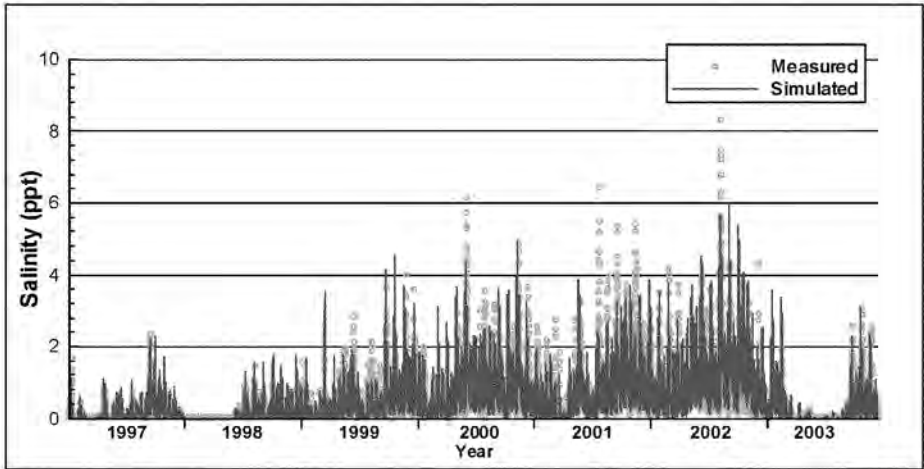


Figure M-3 7-Year Salinity Comparison at USGS 02198791 F&W Docks (mid-depth)

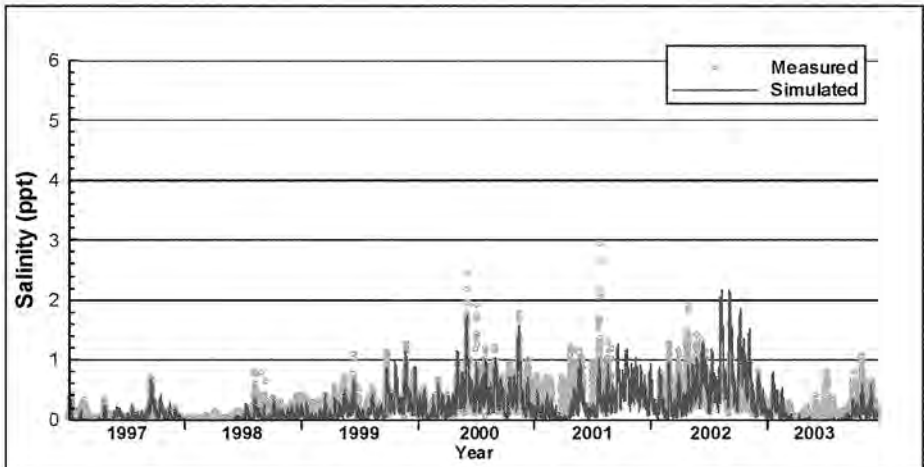


Figure M-4 7-Year Salinity Comparison at USGS 021989784 Lucknow Canal (mid-depth)



**APPENDIX N 1999 AMMONIA COMPARISONS**



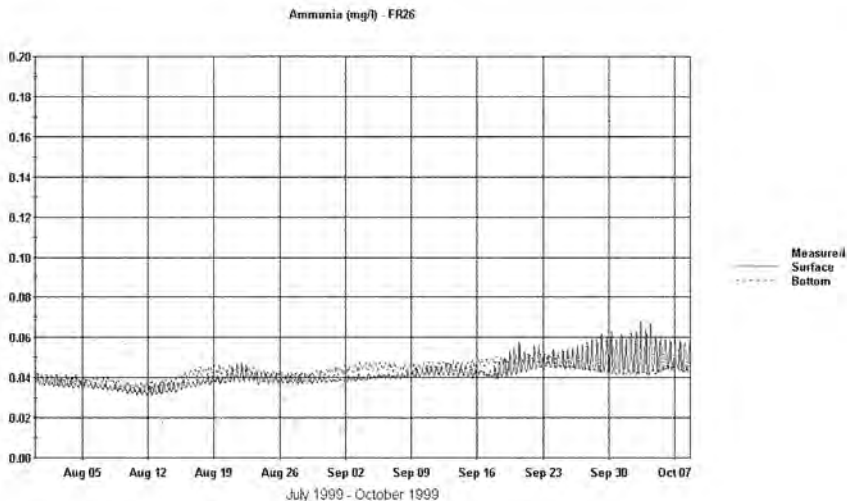


Figure N-1 Ammonia Calibration at FR-26 for July 31 through October 13, 1999

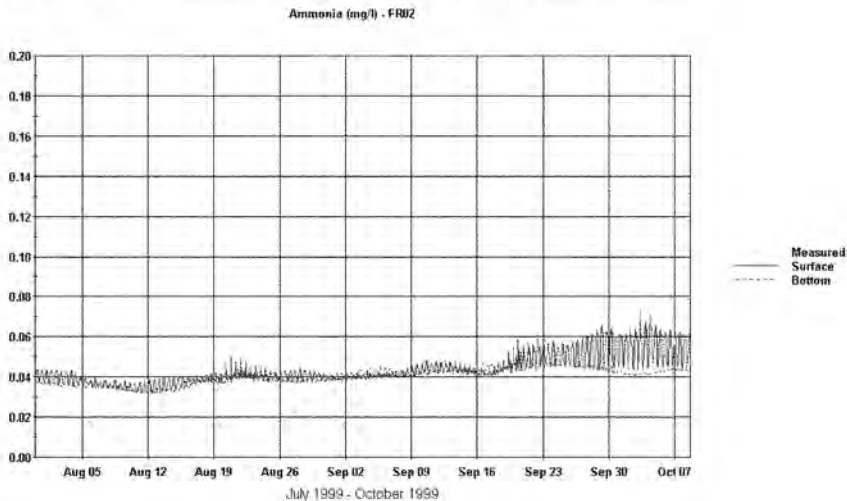


Figure N-2 Ammonia Calibration at FR-02 for July 31 through October 13, 1999

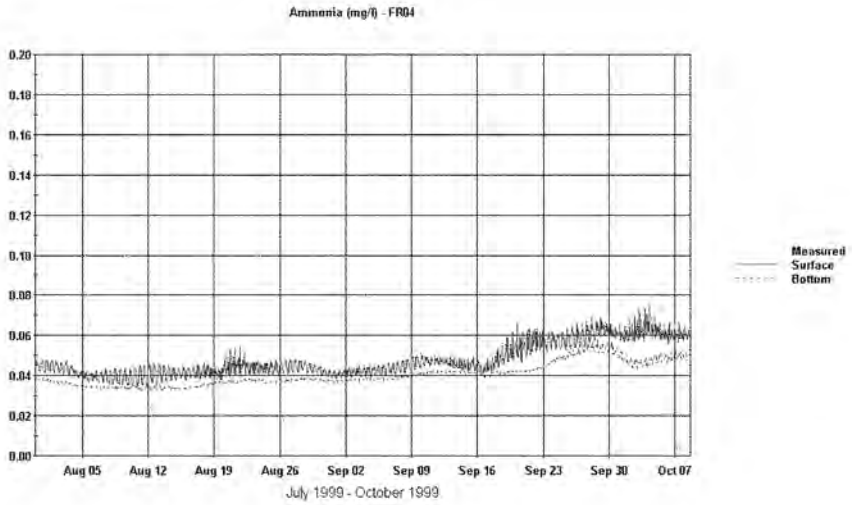


Figure N-3 Ammonia Calibration at FR-04 for July 31 through October 13, 1999

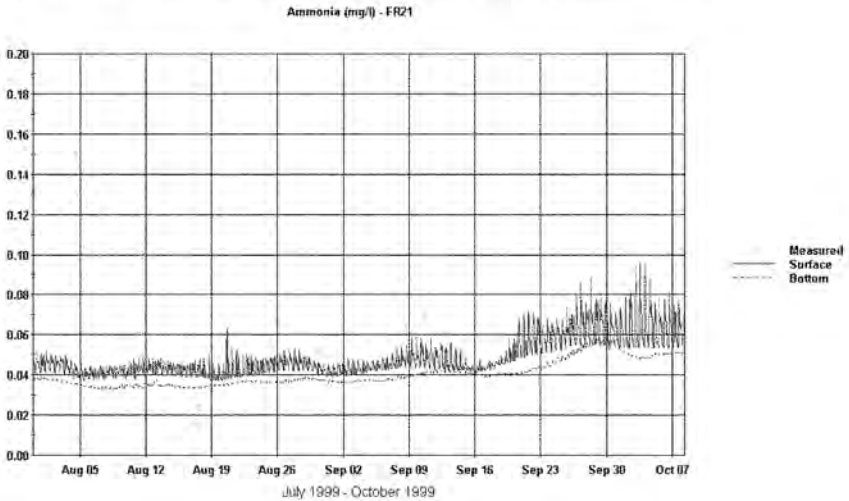


Figure N-4 Ammonia Calibration at FR-21 for July 31 through October 13, 1999

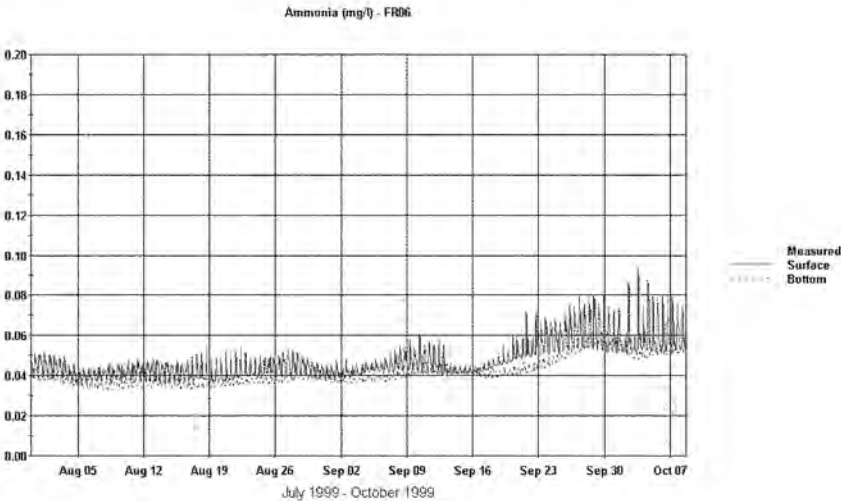


Figure N-5 Ammonia Calibration at FR-06 for August 1, 1999 through October 14, 1999

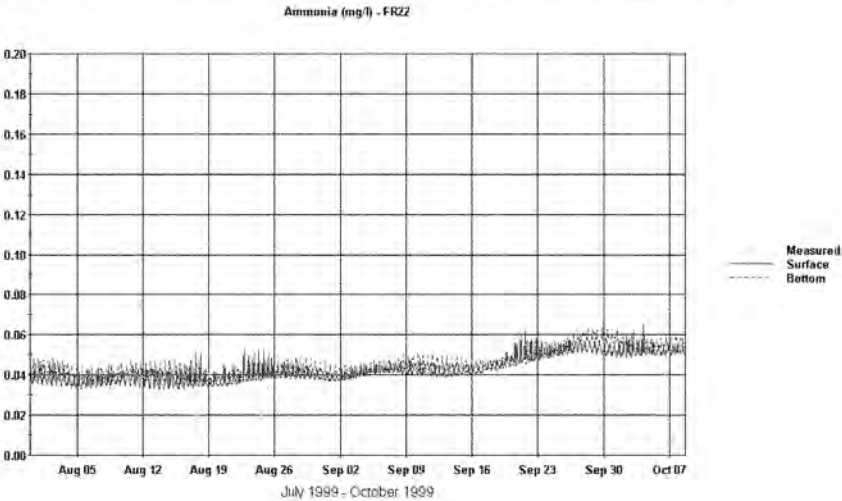


Figure N-6 Ammonia Calibration at FR-22 for July 31 through October 13, 1999

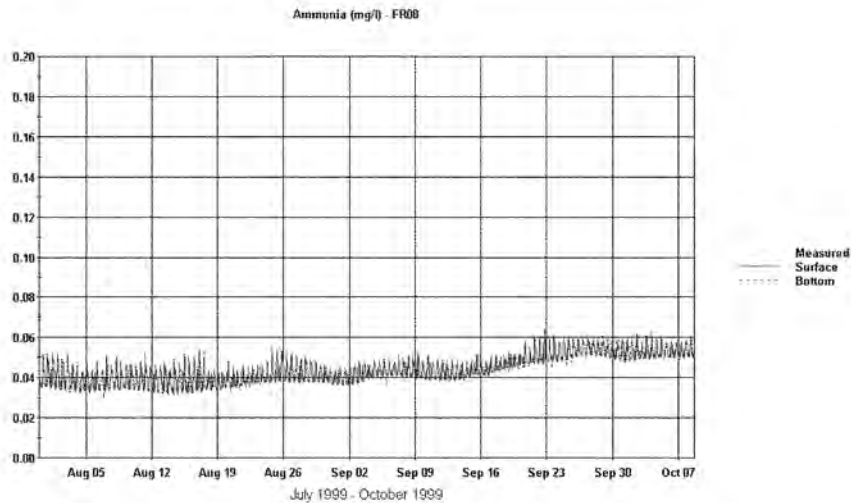


Figure N-7 Ammonia Calibration at FR-08 for July 31 through October 13, 1999

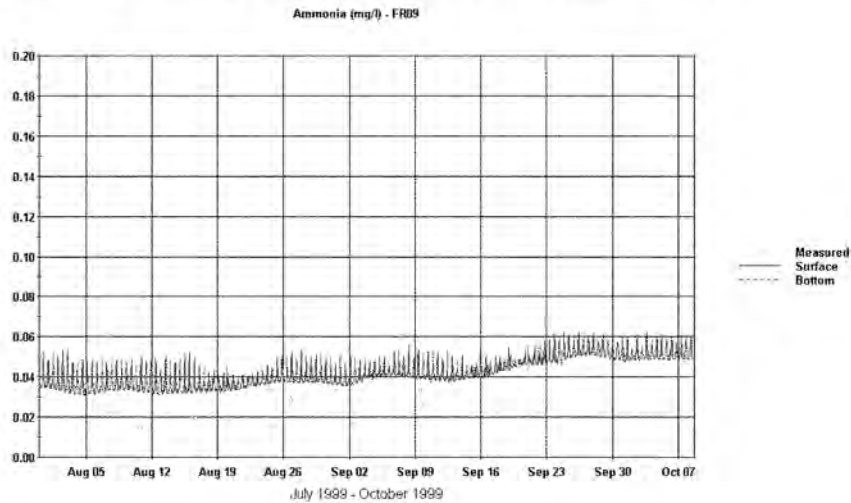


Figure N-8 Ammonia Calibration at FR-09 for July 31 through October 13, 1999

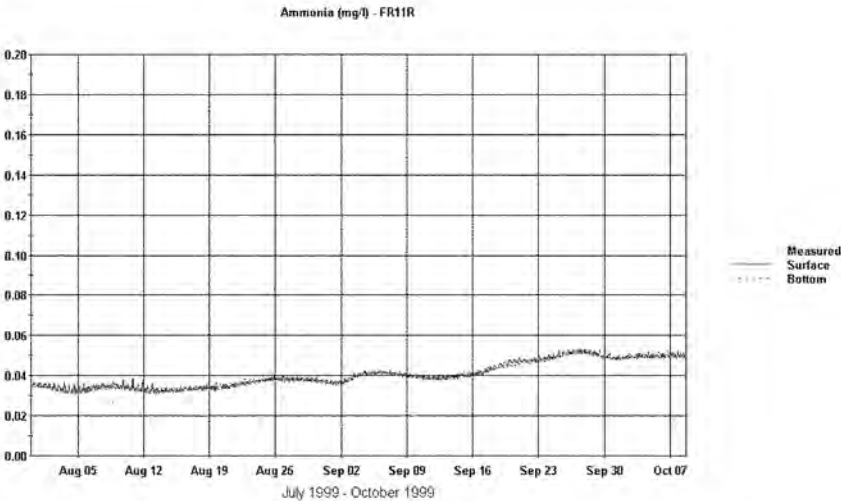


Figure N-9 Ammonia Calibration at FR-11R for July 31 through October 13, 1999

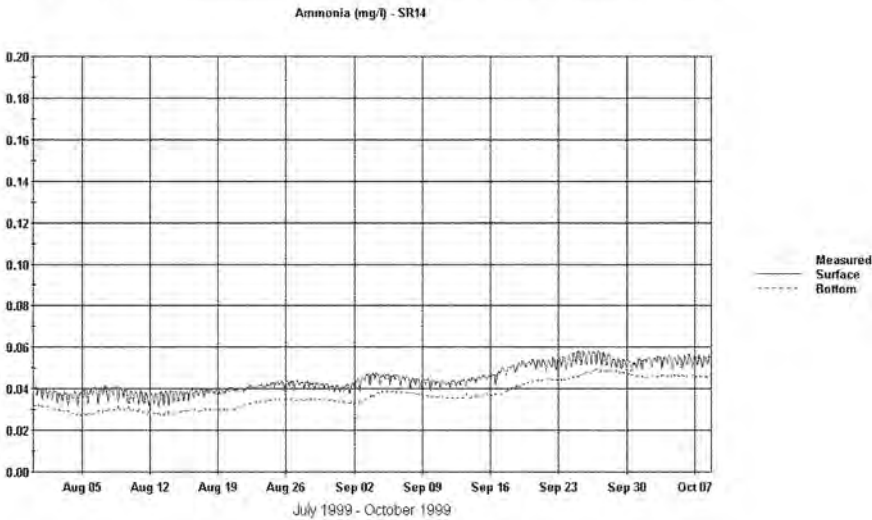


Figure N-10 Ammonia Calibration at SR-14 for July 31 through October 13, 1999

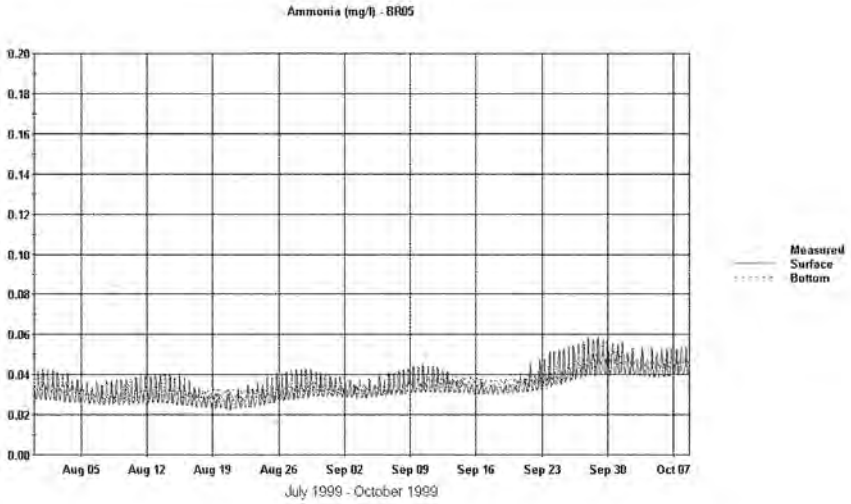


Figure N-11 Ammonia Calibration at BR-05 for July 31 through October 13, 1999

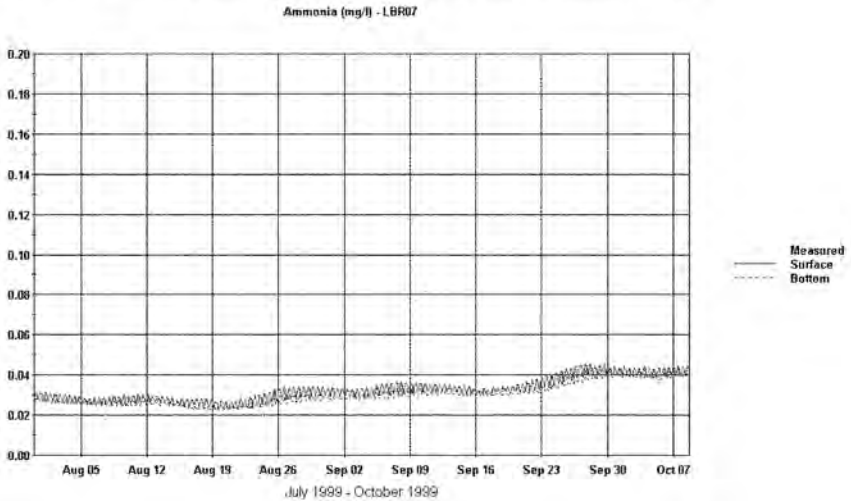


Figure N-12 Ammonia Calibration at LBR-07 for July 31 through October 13, 1999



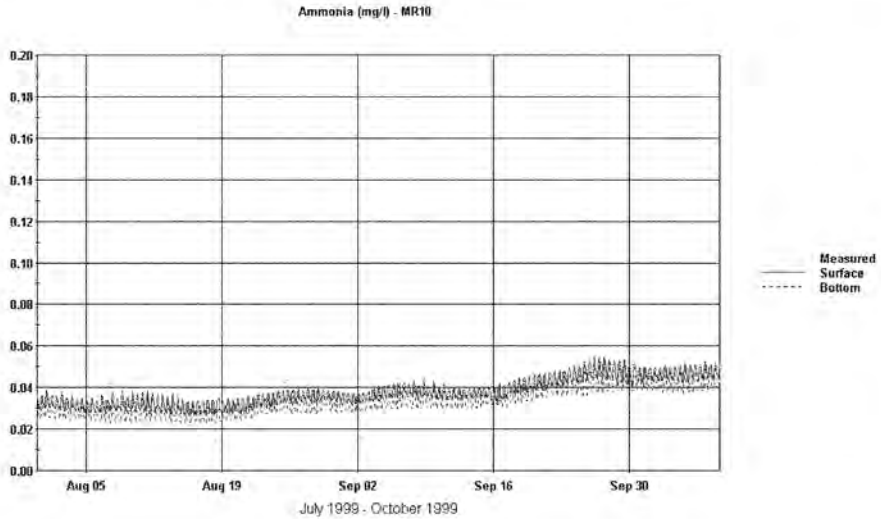


Figure N-13 Ammonia Calibration at MR-10 for July 31 through October 13, 1999

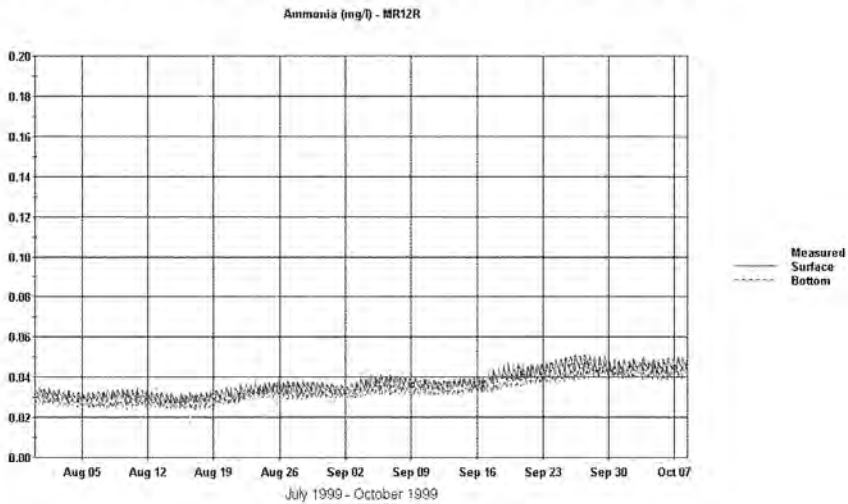


Figure N-14 Ammonia Calibration at MR-12R for July 31 through October 13, 1999



**APPENDIX O    1999 CBOD<sub>u</sub> COMPARISONS**



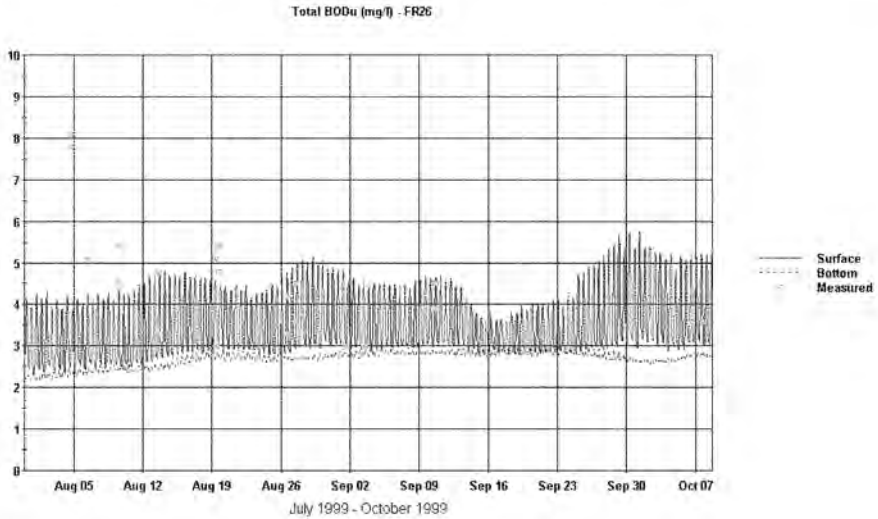


Figure O-1 CBODu Calibration at FR-26 for July 31 through October 13, 1999

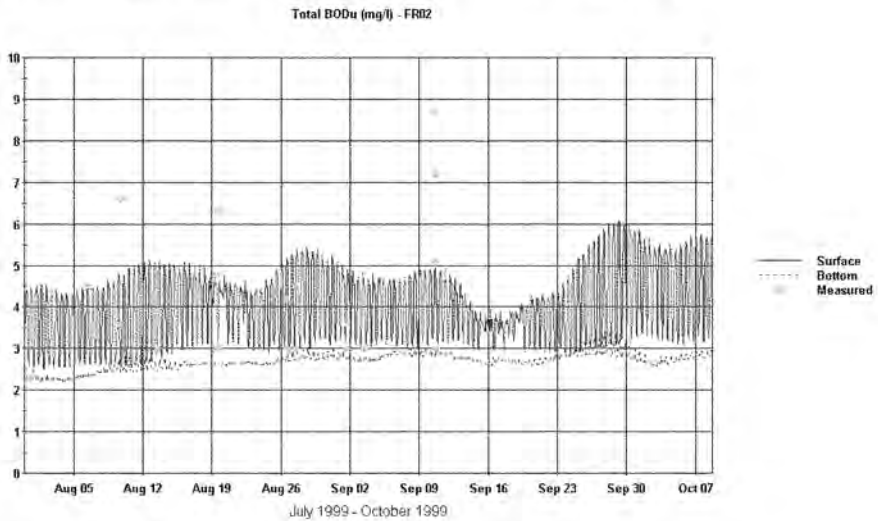


Figure O-2 CBODu Calibration at FR-02 for July 31 through October 13, 1999

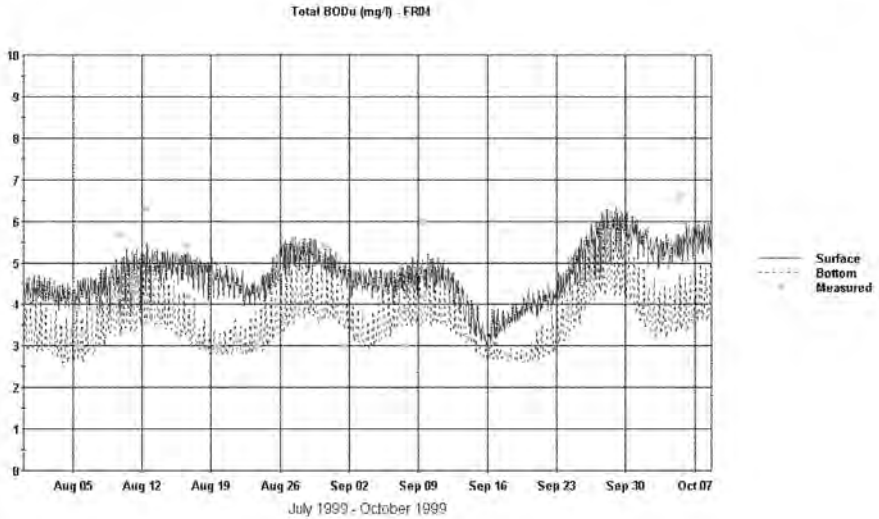


Figure O-3 CBODu Calibration at FR-04 for July 31 through October 13, 1999

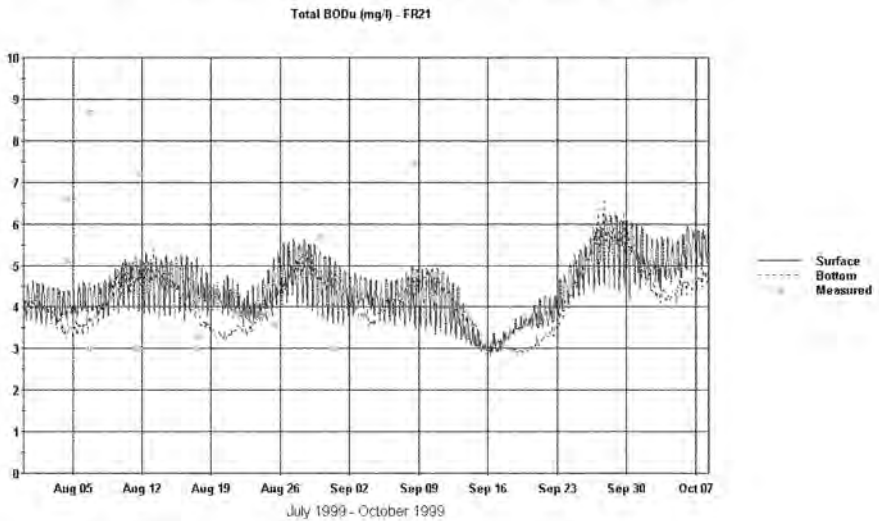


Figure O-4 CBODu Calibration at FR-21 for July 31 through October 13, 1999

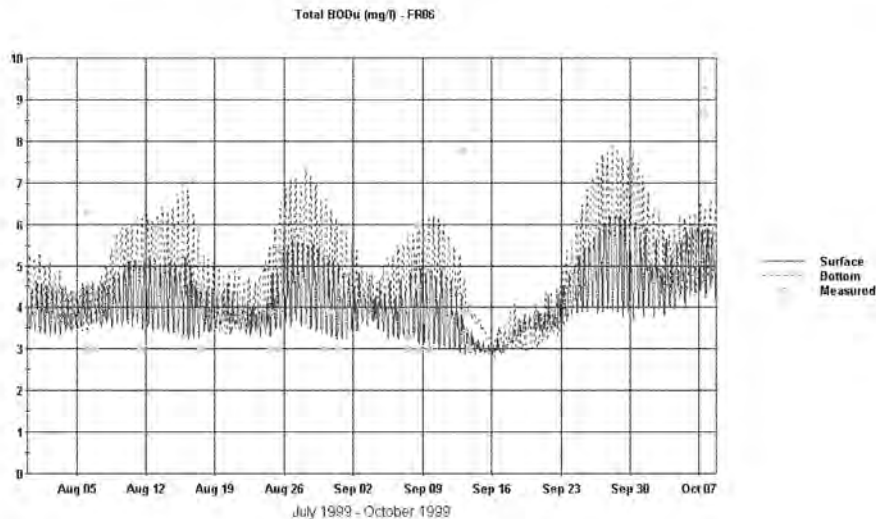


Figure O-5 CBODu Calibration at FR-06 for July 31 through October 13, 1999

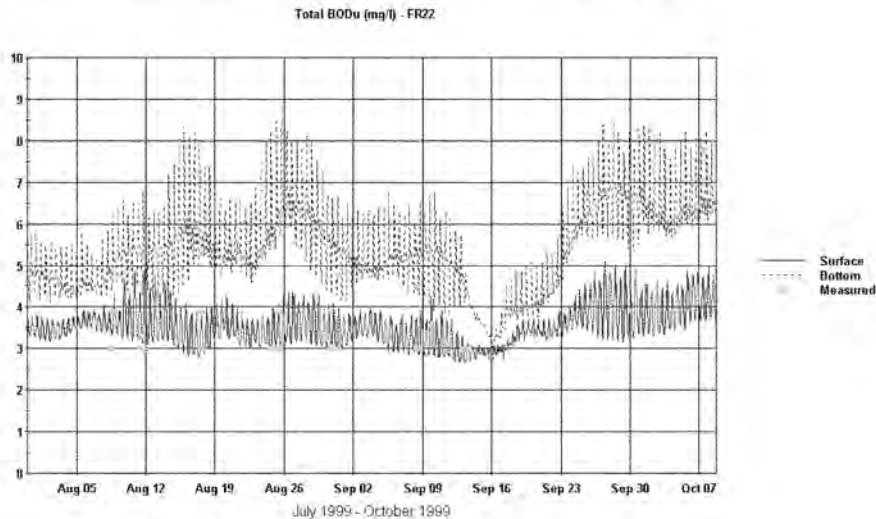


Figure O-6 CBODu Calibration at FR-22 for July 31 through October 13, 1999

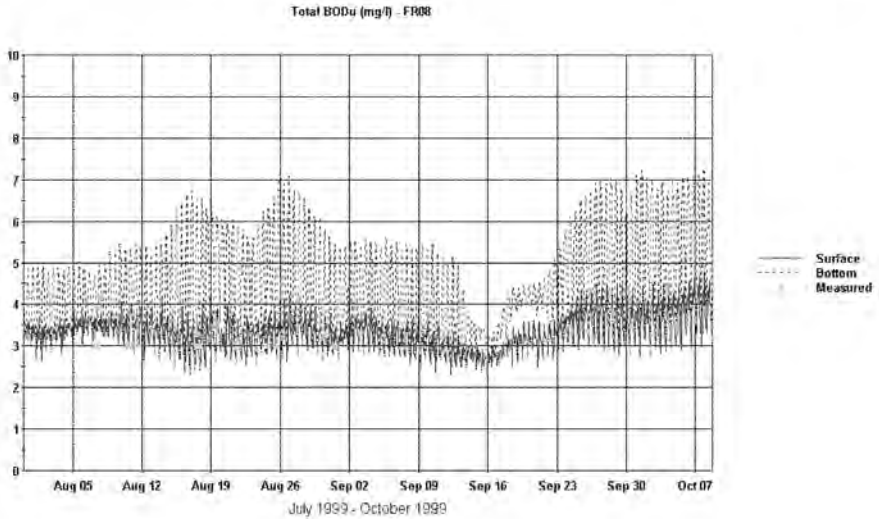


Figure O-7 CBODu Calibration at FR-08 for July 31 through October 13, 1999

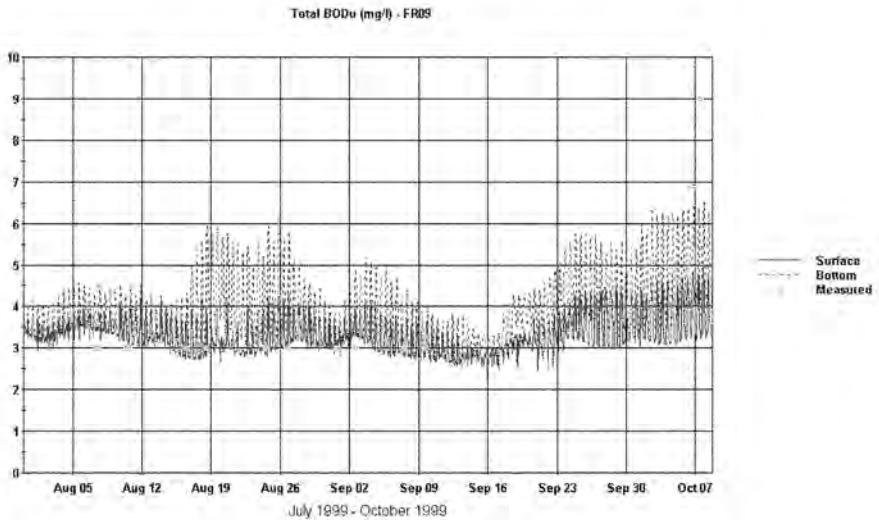


Figure O-8 CBODu Calibration at FR-09 for July 31 through October 13, 1999



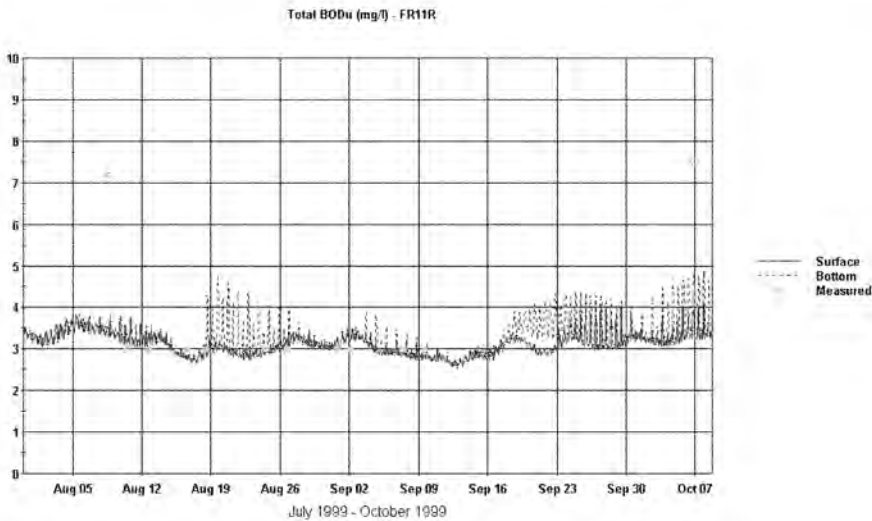


Figure O-9 CBODu Calibration at FR-11R for July 31 through October 13, 1999

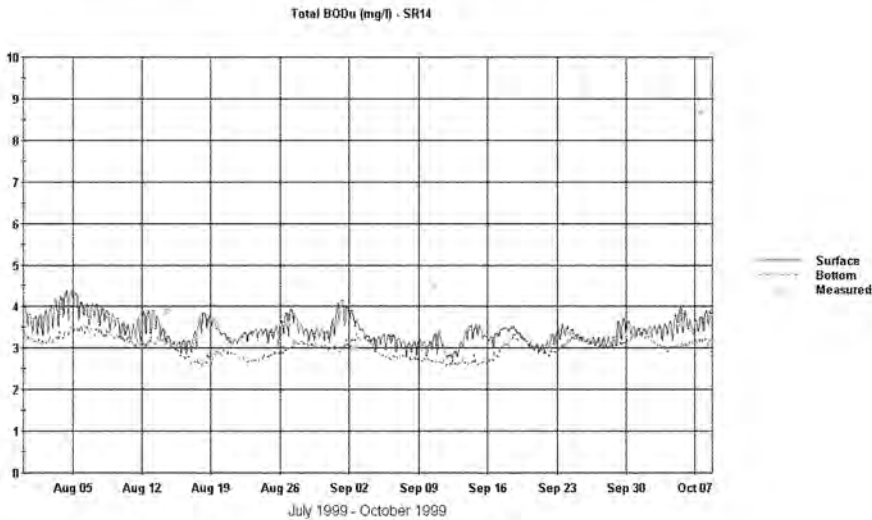


Figure O-10 CBODu Calibration at SR-14 for July 31 through October 13, 1999

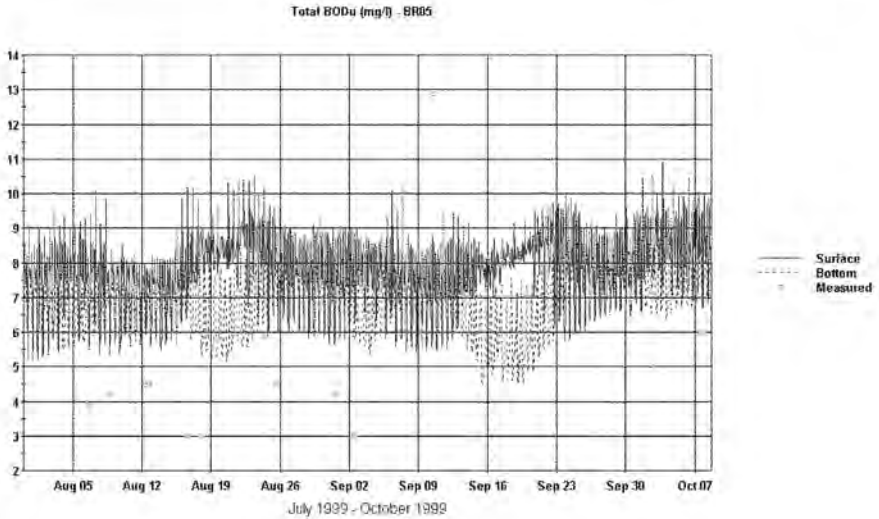


Figure O-11 CBODu Calibration at BR-05 for July 31 through October 13, 1999

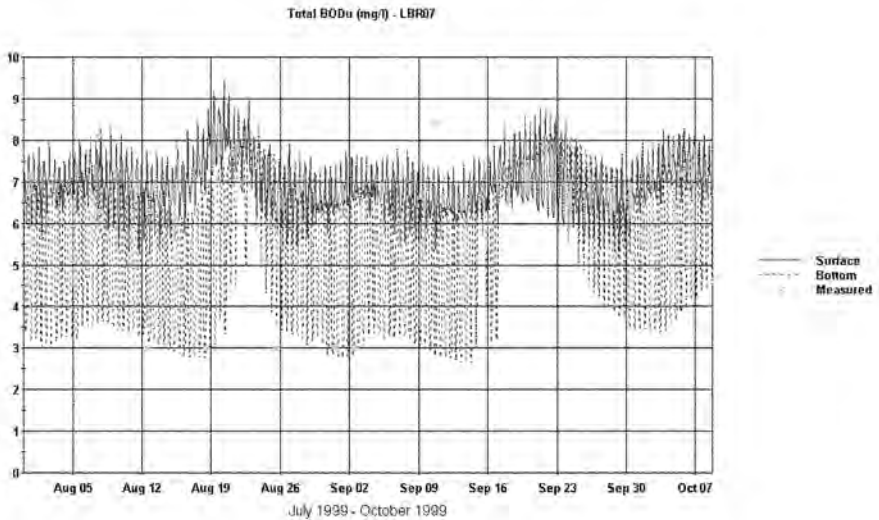


Figure O-12 CBODu Calibration at LBR-07 for July 31 through October 13, 1999

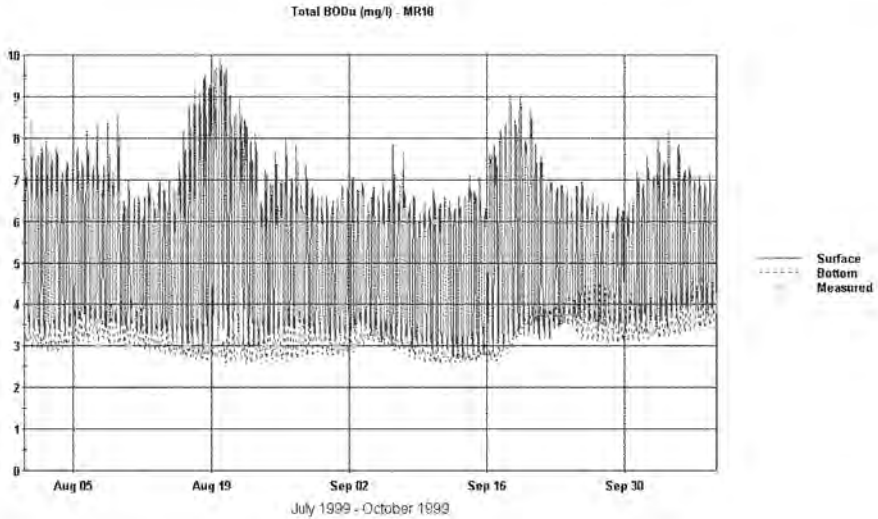


Figure O-13 CBODu Calibration at MR-10 for July 31 through October 13, 1999

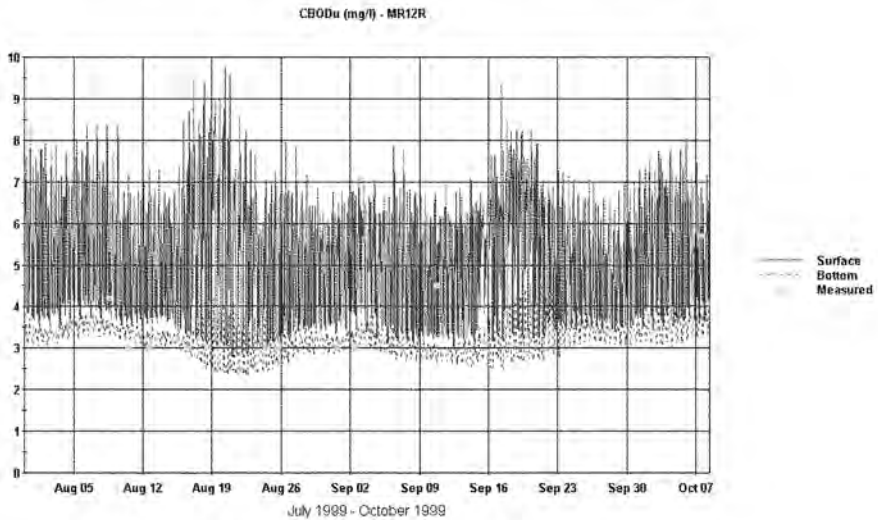


Figure O-14 CBODu Calibration at MR-12R for July 31 through October 13, 1999



**APPENDIX P    1999 DISSOLVED OXYGEN: USGS CORRECTED  
DATA**



Table P-1 Summary Percentiles for Dissolved Oxygen (mg/l) for July 31, 1999 through October 13, 1999

| July 31 - October 13, 1999<br>[Julian Days 213-285] |        |               |            |               |               |            |               |               |            |               |
|-----------------------------------------------------|--------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                            | Depth* | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                     |        | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                               | S      | 3.4           | 5.2        | 6.8           | 4.1           | 4.8        | 5.2           | 0.7           | -0.4       | -1.6          |
| FR-02                                               | B      | 3.2           | 3.7        | 4.4           | 3.9           | 4.2        | 4.4           | 0.7           | 0.5        | 0.0           |
| FR-04                                               | S      | 3.5           | 4.3        | 5.3           | 3.6           | 4.2        | 4.9           | 0.1           | -0.1       | -0.4          |
| FR-04                                               | B      | 2.5           | 3.6        | 5.2           | 3.2           | 3.6        | 4.3           | 0.7           | 0.0        | -0.9          |
| FR-06                                               | S      | 4.4           | 6.0        | 7.2           | 4.4           | 5.4        | 6.1           | 0.0           | -0.6       | -1.1          |
| FR-06                                               | B      | 2.2           | 3.6        | 3.9           | 3.0           | 3.7        | 4.0           | 0.8           | 0.1        | 0.1           |
| FR-08                                               | S      | 4.4           | 6.0        | 7.2           | 4.4           | 5.4        | 6.1           | 0.0           | -0.6       | -1.1          |
| FR-08                                               | B      | 2.7           | 4.0        | 6.5           | 3.1           | 3.8        | 4.7           | 0.4           | -0.2       | -1.8          |
| FR-09                                               | S      | 3.8           | 5.3        | 6.4           | 4.6           | 5.6        | 6.3           | 0.8           | 0.3        | -0.1          |
| FR-09                                               | B      | 3.4           | 5.2        | 6.4           | 3.9           | 4.7        | 5.7           | 0.5           | -0.5       | -0.7          |
| MR-10                                               | S      | 4.5           | 5.5        | 6.3           | 5.5           | 6.2        | 6.7           | 1.0           | 0.7        | 0.4           |
| FR-11R                                              | B      | 4.8           | 6.3        | 6.9           | 4.9           | 5.8        | 6.4           | 0.1           | -0.5       | -0.5          |
| SR-14                                               | B      | 6.0           | 6.6        | 7.5           | 5.5           | 6.1        | 6.5           | -0.5          | -0.5       | -1.0          |
| SR-16                                               | B      | 6.5           | 7.0        | 7.4           | 6.4           | 7.0        | 7.3           | -0.2          | 0.0        | -0.2          |
| FR-21                                               | S      | 3.1           | 4.4        | 5.0           | 3.9           | 4.8        | 5.4           | 0.8           | 0.4        | 0.4           |
| FR-21                                               | B      | 2.5           | 3.4        | 4.2           | 2.9           | 3.8        | 4.1           | 0.4           | 0.4        | -0.1          |
| FR-22                                               | S      | 4.1           | 5.1        | 6.2           | 4.5           | 5.5        | 6.0           | 0.4           | 0.4        | -0.2          |
| FR-22                                               | B      | 2.7           | 3.7        | 5.2           | 2.9           | 3.8        | 4.5           | 0.2           | 0.1        | -0.7          |

\* S = Surface

B = Bottom

Table P-2 Summary Statistics for Dissolved Oxygen (mg/l) for July 31, 1999 through October 13, 1999

| July 31 - October 13, 1999<br>[Julian Days 213-285] |       |       |       |      |      |          |           |           |            |                |
|-----------------------------------------------------|-------|-------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Station                                             | Depth | N     | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-02                                               | S     | 8116  | -0.40 | 1.08 | 1.33 | 5.12     | 1.29      | 4.72      | 0.40       | 0.05           |
| FR-02                                               | B     | 794   | 0.45  | 0.53 | 0.64 | 3.73     | 0.42      | 4.17      | 0.18       | 0.00           |
| FR-04                                               | S     | 9750  | -0.06 | 0.68 | 0.90 | 4.29     | 0.91      | 4.24      | 0.51       | 0.10           |
| FR-04                                               | B     | 10643 | -0.06 | 0.63 | 0.86 | 3.74     | 1.02      | 3.67      | 0.40       | 0.32           |
| FR-06                                               | S     | 11922 | -0.54 | 0.99 | 1.22 | 5.85     | 1.12      | 5.32      | 0.61       | 0.10           |
| FR-06                                               | B     | 15018 | 0.23  | 0.33 | 0.46 | 3.33     | 0.65      | 3.56      | 0.38       | 0.67           |
| FR-08                                               | S     | 11922 | -0.54 | 0.99 | 1.22 | 5.85     | 1.12      | 5.32      | 0.61       | 0.10           |
| FR-08                                               | B     | 4896  | -0.46 | 0.99 | 1.34 | 4.36     | 1.52      | 3.89      | 0.61       | 0.36           |
| FR-09                                               | S     | 16868 | 0.36  | 0.78 | 0.93 | 5.17     | 0.95      | 5.53      | 0.61       | 0.22           |
| FR-09                                               | B     | 15358 | -0.26 | 0.73 | 0.91 | 5.00     | 1.19      | 4.74      | 0.71       | 0.48           |
| MR-10                                               | S     | 15610 | 0.73  | 0.85 | 1.03 | 5.43     | 0.69      | 6.16      | 0.51       | 0.08           |
| FR-11R                                              | B     | 14761 | -0.36 | 0.67 | 0.82 | 6.10     | 0.84      | 5.74      | 0.60       | 0.26           |
| SR-14                                               | B     | 12362 | -0.63 | 0.80 | 1.02 | 6.71     | 0.55      | 6.07      | 0.42       | 0.12           |
| FR-21                                               | S     | 18534 | 0.50  | 0.65 | 0.87 | 4.22     | 0.75      | 4.73      | 0.57       | 0.21           |
| FR-21                                               | B     | 9451  | 0.17  | 0.37 | 0.51 | 3.42     | 0.74      | 3.59      | 0.47       | 0.61           |
| FR-22                                               | S     | 18948 | 0.22  | 0.57 | 0.70 | 5.14     | 0.85      | 5.36      | 0.55       | 0.39           |
| FR-22                                               | B     | 12379 | -0.05 | 0.51 | 0.68 | 3.78     | 0.96      | 3.73      | 0.58       | 0.51           |

\* S = Surface

B = Bottom

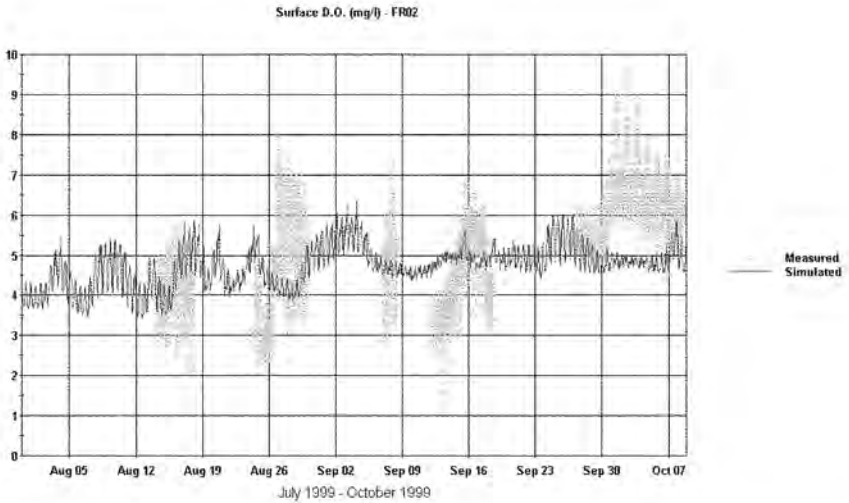


Figure P-1 Dissolved Oxygen Calibration at FR-02 (Surface) for July 31 through October 13, 1999

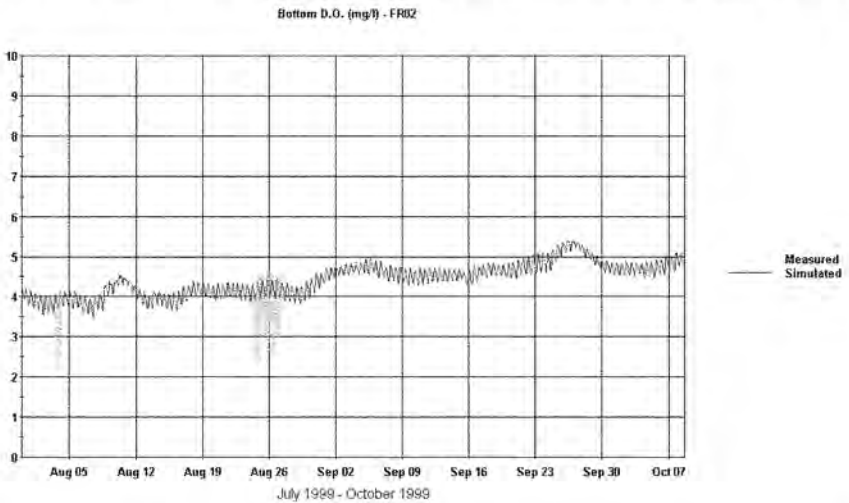


Figure P-2 Dissolved Oxygen Calibration at FR-02 (Bottom) for July 31 through October 13, 1999



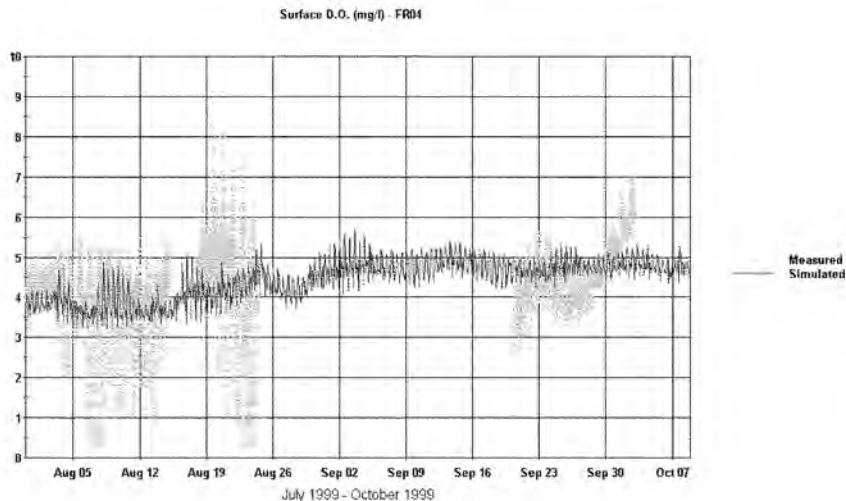


Figure P-3 Dissolved Oxygen Calibration at FR-04 (Surface) for July 31 through October 13, 1999

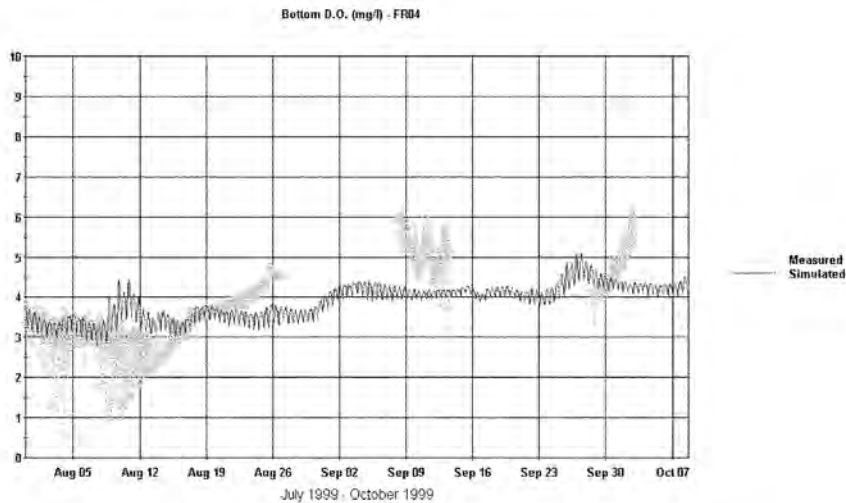


Figure P-4 Dissolved Oxygen Calibration at FR-04 (Bottom) for July 31 through October 13, 1999

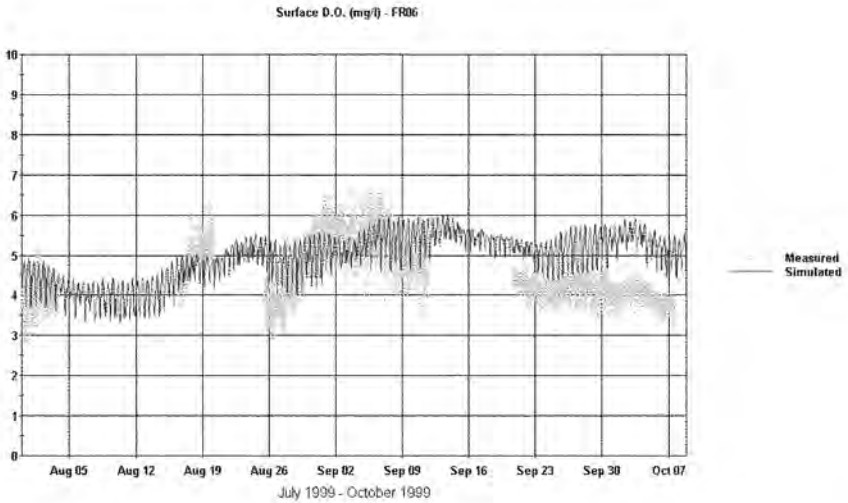


Figure P-5 Dissolved Oxygen Calibration at FR-06 (Surface) for July 31 through October 13, 1999

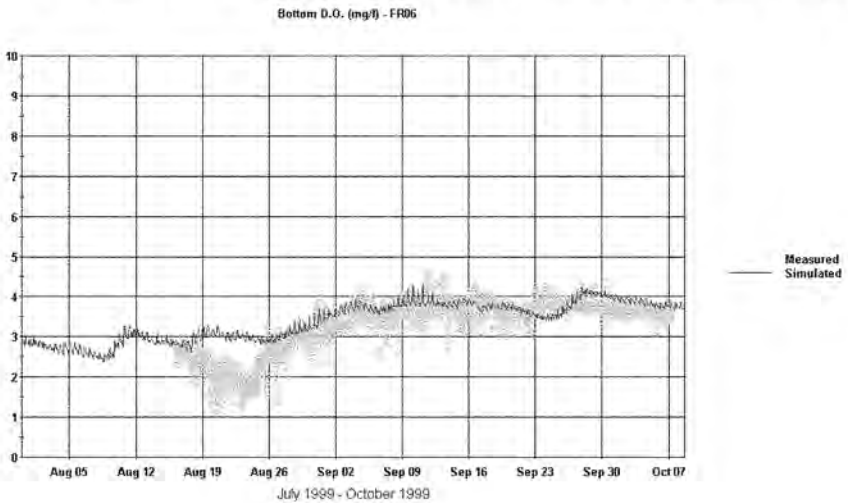


Figure P-6 Dissolved Oxygen Calibration at FR-06 (Bottom) for July 31 through October 13, 1999

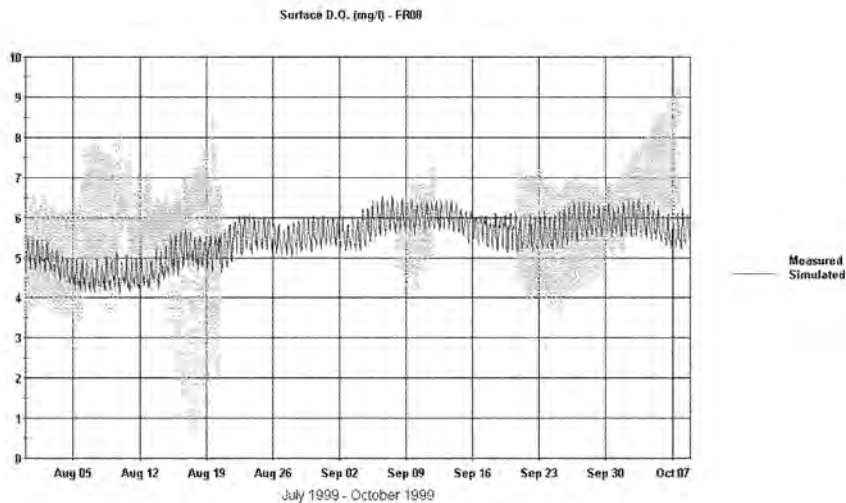


Figure P-7 Dissolved Oxygen Calibration at FR-08 (Surface) for July 31 through October 13, 1999

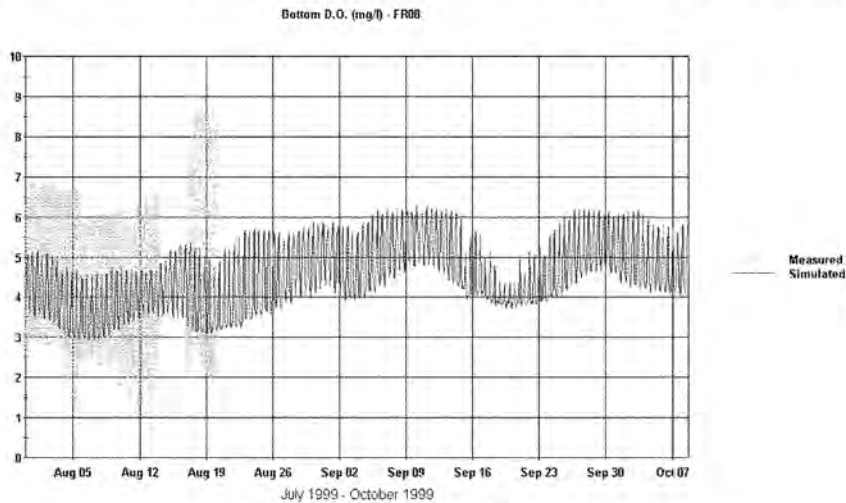


Figure P-8 Dissolved Oxygen Calibration at FR-08 (Bottom) for July 31 through October 13, 1999

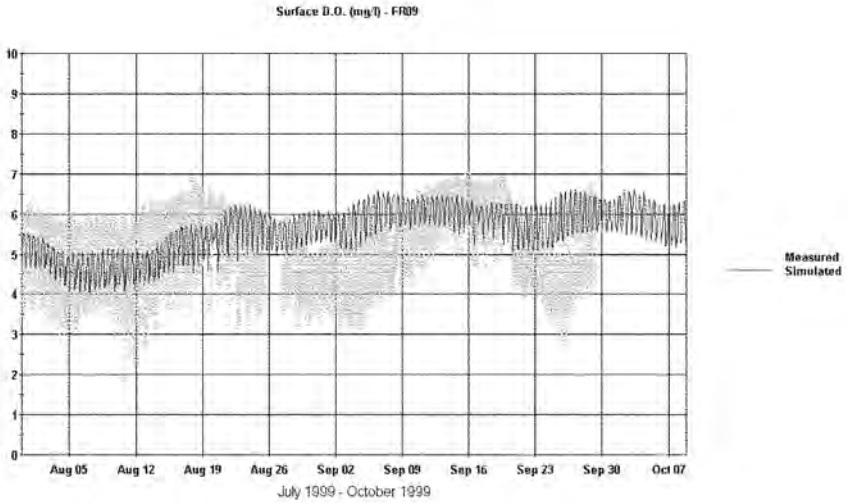


Figure P-9 Dissolved Oxygen Calibration at FR-09 (Surface) for July 31 through October 13, 1999

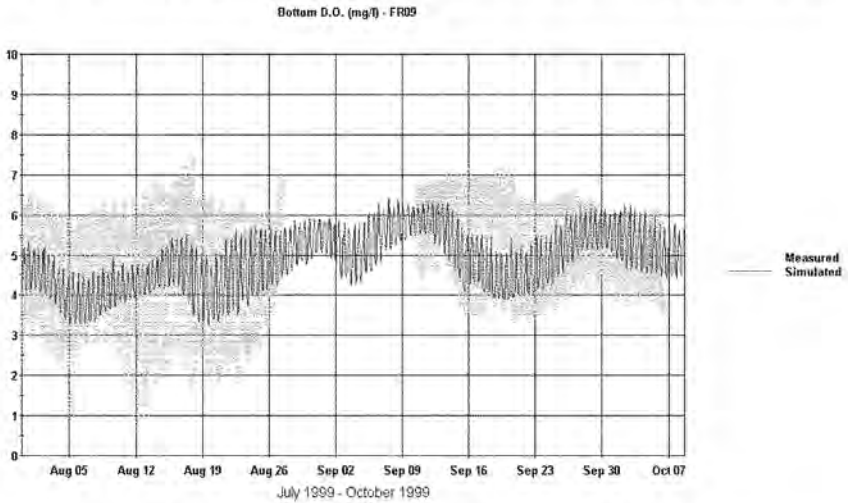


Figure P-10 Dissolved Oxygen Calibration at FR-09 (Bottom) for July 31 through October 13, 1999

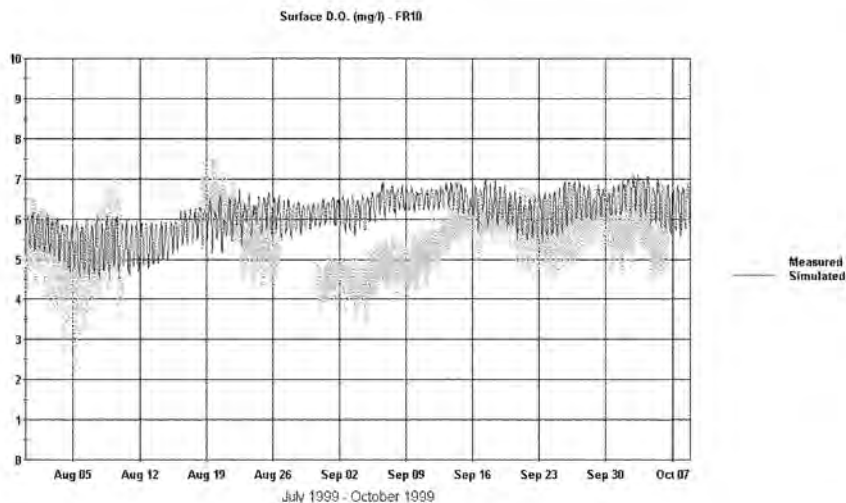


Figure P-11 Dissolved Oxygen Calibration at MR-10 (Surface) for July 31 through October 13, 1999

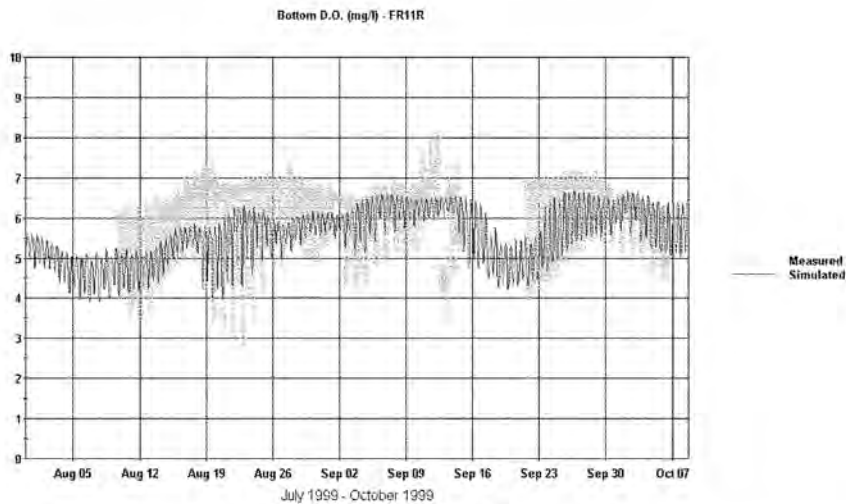


Figure P-12 Dissolved Oxygen Calibration at FR-11R (Bottom) for July 31 through October 13, 1999

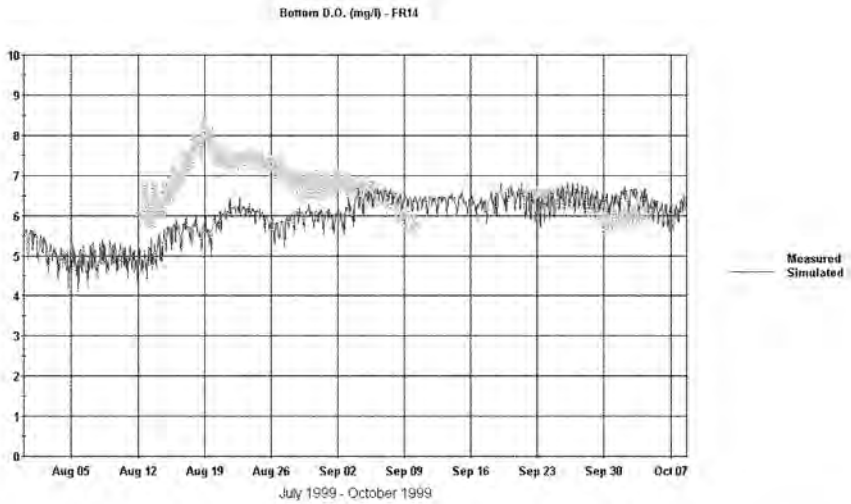


Figure P-13 Dissolved Oxygen Calibration at SR-14 (Bottom) for July 31 through October 13, 1999

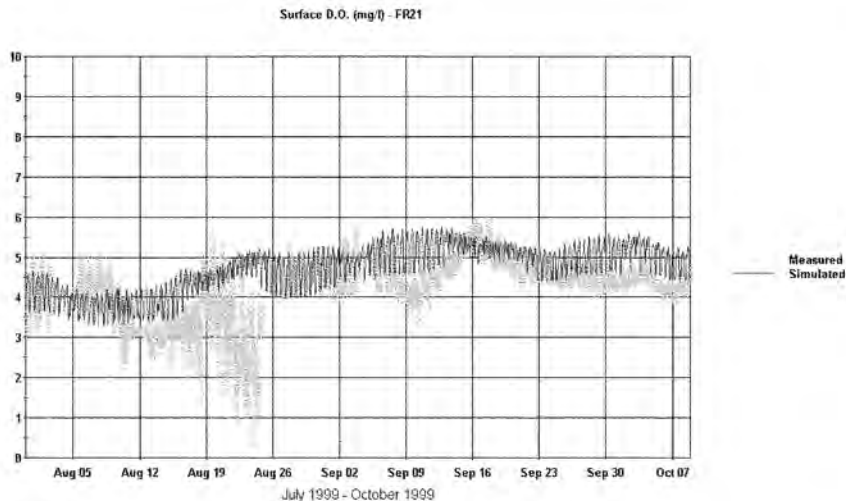


Figure P-14 Dissolved Oxygen Calibration at FR-21 (Surface) for July 31 through October 13, 1999

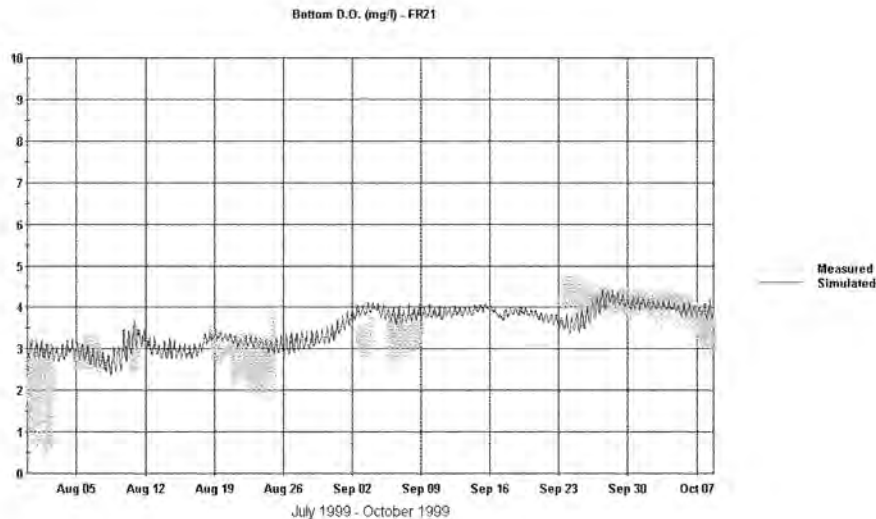


Figure P-15 Dissolved Oxygen Calibration at FR-21 (Bottom) for July 31 through October 13, 1999

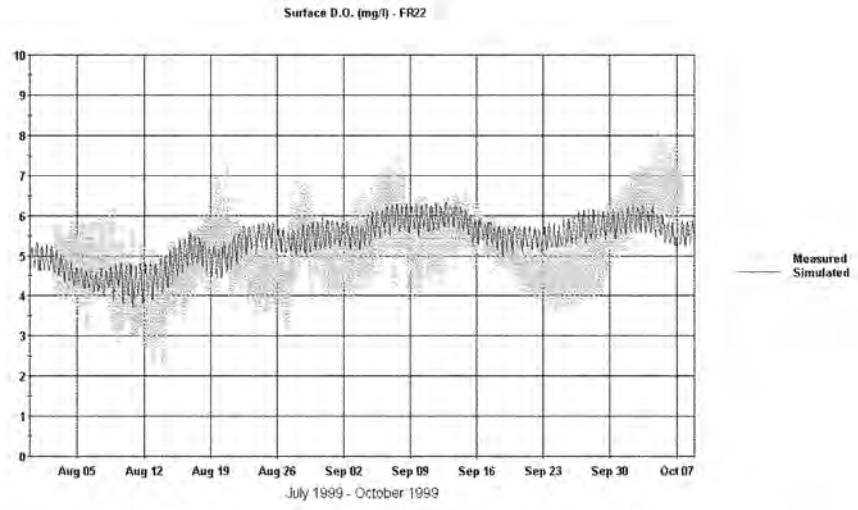


Figure P-16 Dissolved Oxygen Calibration at FR-22 (Surface) for July 31 through October 13, 1999

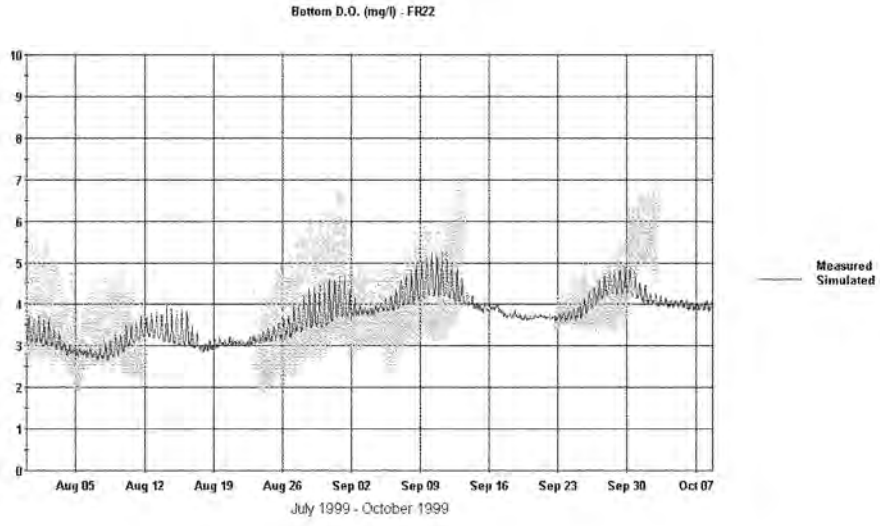




Figure P-17      Dissolved Oxygen Calibration at FR-22 (Bottom) for July 31 through October 13, 1999

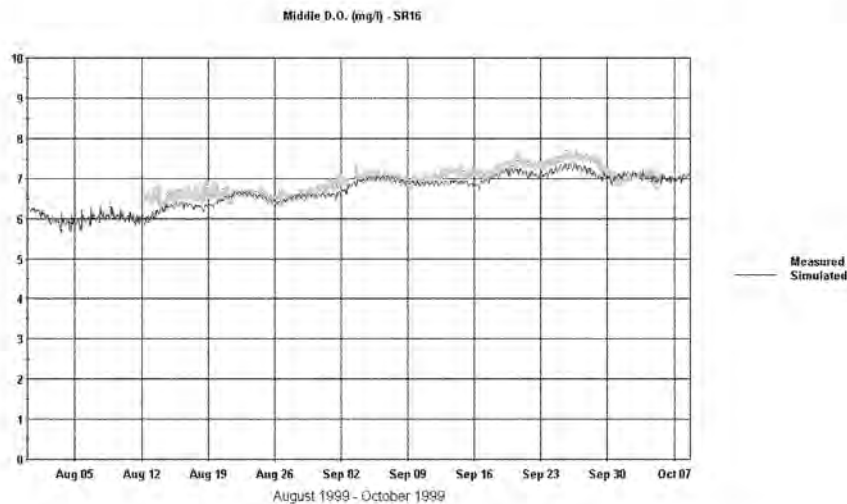


Figure P-18      Dissolved Oxygen Calibration at SR-16 (Mid-Depth) for July 31 through October 13, 1999

Table P-3 Summary Percentiles for Dissolved Oxygen (mg/l) for July 31, 1999 through August 15, 1999

| July 31 - August 15, 1999<br>(Julian Days 213-226) |        |               |            |               |               |            |               |               |            |               |
|----------------------------------------------------|--------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                           | Depth* | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                    |        | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                              | S      | 3.1           | 3.8        | 4.5           | 3.6           | 3.9        | 4.5           | 0.5           | 0.1        | 0.0           |
| FR-02                                              | B      |               |            |               |               |            |               |               |            |               |
| FR-04                                              | S      | 3.1           | 4.1        | 4.6           | 3.5           | 3.7        | 4.2           | 0.4           | -0.4       | -0.4          |
| FR-04                                              | B      | 2.1           | 3.0        | 3.4           | 3.1           | 3.4        | 3.8           | 1.0           | 0.4        | 0.4           |
| FR-06                                              | S      | 3.6           | 4.0        | 4.4           | 3.9           | 4.4        | 4.8           | 0.3           | 0.4        | 0.4           |
| FR-06                                              | B      |               |            |               |               |            |               |               |            |               |
| FR-08                                              | S      | 4.3           | 5.8        | 7.0           | 4.3           | 4.7        | 5.1           | 0.1           | -1.1       | -1.9          |
| FR-08                                              | B      | 2.8           | 4.0        | 6.3           | 3.1           | 3.8        | 4.7           | 0.3           | -0.2       | -1.6          |
| FR-09                                              | S      | 3.6           | 4.7        | 6.0           | 4.3           | 4.8        | 5.2           | 0.7           | 0.1        | -0.8          |
| FR-09                                              | B      | 3.1           | 4.5        | 6.0           | 3.6           | 4.2        | 4.8           | 0.5           | -0.3       | -1.2          |
| MR-10                                              | S      | 4.3           | 5.1        | 6.0           | 4.8           | 5.6        | 6.0           | 0.5           | 0.5        | 0.0           |
| FR-11R                                             | B      | 4.1           | 5.7        | 6.2           | 4.3           | 4.9        | 5.2           | 0.2           | -0.8       | -1.0          |
| SR-14                                              | B      |               |            |               |               |            |               |               |            |               |
| SR-16                                              | B      | 6.5           | 7.0        | 7.4           | 6.4           | 7.0        | 7.3           | -0.2          | 0.0        | -0.2          |
| FR-21                                              | S      | 3.0           | 3.9        | 4.5           | 3.5           | 3.9        | 4.3           | 0.5           | 0.0        | -0.2          |
| FR-21                                              | B      | 1.5           | 2.7        | 3.1           | 2.7           | 2.9        | 3.2           | 1.2           | 0.2        | 0.1           |
| FR-22                                              | S      | 3.4           | 4.4        | 5.3           | 4.1           | 4.5        | 4.8           | 0.7           | 0.1        | -0.5          |
| FR-22                                              | B      | 2.5           | 3.0        | 4.0           | 2.8           | 3.0        | 3.4           | 0.3           | 0.0        | -0.6          |

\* S = Surface  
B = Bottom

Table P-4 Summary Statistics for Dissolved Oxygen (mg/l) for July 31, 1999 through August 15, 1999

| July 31 - August 15, 1999<br>(Julian Days 213-226) |       |      |       |      |      |          |           |           |            |                |
|----------------------------------------------------|-------|------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Station                                            | Depth | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-02                                              | S     | 254  | 0.16  | 0.38 | 0.45 | 3.81     | 0.52      | 3.97      | 0.35       | 0.34           |
| FR-02                                              | B     |      |       |      |      |          |           |           |            |                |
| FR-04                                              | S     | 4286 | -0.14 | 0.55 | 0.76 | 3.93     | 0.76      | 3.80      | 0.28       | 0.05           |
| FR-04                                              | B     | 4234 | 0.58  | 0.64 | 0.95 | 2.86     | 0.58      | 3.43      | 0.29       | 0.20           |
| FR-06                                              | S     | 1100 | 0.36  | 0.40 | 0.47 | 4.04     | 0.35      | 4.39      | 0.31       | 0.30           |
| FR-06                                              | B     |      |       |      |      |          |           |           |            |                |
| FR-08                                              | S     | 4286 | -0.97 | 1.15 | 1.38 | 5.65     | 0.99      | 4.68      | 0.31       | 0.03           |
| FR-08                                              | B     | 4032 | -0.40 | 0.89 | 1.14 | 4.30     | 1.31      | 3.90      | 0.58       | 0.36           |
| FR-09                                              | S     | 4286 | -0.03 | 0.72 | 0.80 | 4.79     | 0.95      | 4.76      | 0.36       | 0.33           |
| FR-09                                              | B     | 4234 | -0.34 | 0.82 | 1.00 | 4.56     | 1.17      | 4.21      | 0.45       | 0.42           |
| MR-10                                              | S     | 2880 | 0.33  | 0.53 | 0.64 | 5.13     | 0.64      | 5.46      | 0.45       | 0.29           |
| FR-11R                                             | B     | 1430 | -0.55 | 0.77 | 0.88 | 5.33     | 0.83      | 4.77      | 0.35       | 0.34           |
| SR-14                                              | B     |      |       |      |      |          |           |           |            |                |
| FR-21                                              | S     | 3654 | 0.17  | 0.53 | 0.65 | 3.74     | 0.58      | 3.90      | 0.31       | 0.01           |
| FR-21                                              | B     | 1768 | 0.38  | 0.48 | 0.72 | 2.56     | 0.62      | 2.94      | 0.20       | 0.05           |
| FR-22                                              | S     | 3525 | 0.09  | 0.50 | 0.63 | 4.37     | 0.71      | 4.46      | 0.28       | 0.24           |
| FR-22                                              | B     | 3422 | -0.11 | 0.38 | 0.51 | 3.15     | 0.60      | 3.03      | 0.24       | 0.36           |

\* S = Surface  
B = Bottom

Table P-5 Summary Percentiles for Dissolved Oxygen (mg/l) for August 15, 1999 through August 30, 1999

| August 16 - August 30, 1999<br>[Julian Days 227-241] |                    |               |            |               |               |            |               |               |            |               |
|------------------------------------------------------|--------------------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                             | Depth <sup>a</sup> | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                      |                    | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                                | S                  | 3.0           | 4.3        | 5.3           | 4.0           | 4.3        | 5.2           | 1.0           | 0.0        | -1.1          |
| FR-02                                                | B                  | 3.3           | 3.7        | 4.4           | 4.0           | 4.2        | 4.4           | 0.7           | 0.5        | 0.0           |
| FR-04                                                | S                  | 3.0           | 4.7        | 5.7           | 3.8           | 4.2        | 4.6           | 0.8           | -0.5       | -1.1          |
| FR-04                                                | B                  | 3.2           | 3.8        | 4.5           | 3.3           | 3.6        | 3.7           | 0.1           | -0.2       | -0.8          |
| FR-06                                                | S                  | 3.7           | 4.6        | 5.3           | 4.3           | 4.8        | 5.2           | 0.6           | 0.2        | -0.1          |
| FR-06                                                | B                  | 1.8           | 2.4        | 3.0           | 2.6           | 3.0        | 3.2           | 1.0           | 0.6        | 0.2           |
| FR-08                                                | S                  | 3.5           | 6.0        | 6.9           | 4.7           | 5.1        | 5.5           | 1.2           | -0.9       | -1.4          |
| FR-08                                                | B                  | 2.4           | 3.4        | 8.3           | 3.1           | 3.5        | 5.0           | 0.7           | 0.1        | -3.3          |
| FR-09                                                | S                  | 4.1           | 5.5        | 6.3           | 4.9           | 5.5        | 6.0           | 0.8           | 0.0        | -0.3          |
| FR-09                                                | B                  | 2.7           | 5.2        | 5.4           | 3.6           | 4.6        | 5.4           | 0.9           | -0.6       | -1.0          |
| MR-10                                                | S                  | 5.1           | 5.9        | 6.7           | 5.6           | 6.1        | 6.5           | 0.5           | 0.2        | -0.2          |
| FR-11R                                               | B                  | 5.0           | 6.7        | 7.0           | 4.9           | 5.6        | 6.1           | -0.1          | -1.1       | -0.9          |
| SR-14                                                | B                  | 6.8           | 7.4        | 7.8           | 5.5           | 5.8        | 6.2           | -1.3          | -1.6       | -1.6          |
| SR-16                                                | B                  | 6.5           | 6.6        | 6.8           | 6.4           | 6.6        | 6.7           | -0.1          | 0.0        | 0.0           |
| FR-21                                                | S                  | 2.2           | 3.5        | 4.7           | 4.0           | 4.6        | 5.0           | 1.8           | 1.1        | 0.3           |
| FR-21                                                | B                  | 2.4           | 2.8        | 3.2           | 3.0           | 3.2        | 3.3           | 0.6           | 0.4        | 0.1           |
| FR-22                                                | S                  | 4.1           | 5.0        | 5.8           | 4.8           | 5.2        | 5.7           | 0.7           | 0.2        | -0.1          |
| FR-22                                                | B                  | 2.2           | 3.0        | 4.7           | 3.2           | 3.4        | 3.9           | 1.0           | 0.4        | -0.8          |

\* S = Surface

B = Bottom

Table P-6 Summary Statistics for Dissolved Oxygen (mg/l) for August 15, 1999 through August 30, 1999

| August 16 - August 30, 1999<br>(Julian Days 227-241) |       |      |       |      |      |             |              |              |               |      |
|------------------------------------------------------|-------|------|-------|------|------|-------------|--------------|--------------|---------------|------|
| Station                                              | Depth | N    | ME    | AME  | RMS  | Mean<br>Obs | StDev<br>Obs | Mean<br>Pred | StDev<br>Pred | R^2  |
| FR-02                                                | S     | 2415 | -0.02 | 1.09 | 1.36 | 4.46        | 1.19         | 4.44         | 0.47          | 0.04 |
| FR-02                                                | B     | 737  | 0.45  | 0.53 | 0.64 | 3.75        | 0.40         | 4.20         | 0.15          | 0.03 |
| FR-04                                                | S     | 1853 | -0.35 | 1.05 | 1.33 | 4.56        | 1.21         | 4.20         | 0.32          | 0.01 |
| FR-04                                                | B     | 3254 | -0.33 | 0.41 | 0.53 | 3.86        | 0.44         | 3.53         | 0.17          | 0.12 |
| FR-06                                                | S     | 2243 | 0.24  | 0.59 | 0.74 | 4.55        | 0.63         | 4.78         | 0.33          | 0.00 |
| FR-06                                                | B     | 3933 | 0.61  | 0.63 | 0.77 | 2.39        | 0.47         | 3.00         | 0.14          | 0.01 |
| FR-08                                                | S     | 1608 | -0.46 | 1.22 | 1.41 | 5.60        | 1.39         | 5.13         | 0.28          | 0.08 |
| FR-08                                                | B     | 864  | -0.78 | 1.47 | 2.02 | 4.61        | 2.25         | 3.83         | 0.71          | 0.43 |
| FR-09                                                | S     | 3742 | 0.13  | 0.66 | 0.81 | 5.36        | 0.84         | 5.50         | 0.39          | 0.11 |
| FR-09                                                | B     | 3654 | -0.29 | 0.87 | 1.03 | 4.85        | 1.39         | 4.56         | 0.63          | 0.59 |
| MR-10                                                | S     | 2315 | 0.16  | 0.65 | 0.75 | 5.88        | 0.63         | 6.04         | 0.34          | 0.00 |
| FR-11R                                               | B     | 4245 | -0.74 | 0.90 | 1.00 | 6.27        | 0.90         | 5.53         | 0.47          | 0.46 |
| SR-14                                                | B     | 4245 | -1.48 | 1.48 | 1.55 | 7.32        | 0.37         | 5.83         | 0.27          | 0.01 |
| FR-21                                                | S     | 3796 | 0.98  | 1.09 | 1.45 | 3.55        | 0.95         | 4.53         | 0.37          | 0.02 |
| FR-21                                                | B     | 1883 | 0.38  | 0.41 | 0.48 | 2.80        | 0.32         | 3.18         | 0.12          | 0.24 |
| FR-22                                                | S     | 4286 | 0.26  | 0.60 | 0.74 | 4.96        | 0.65         | 5.23         | 0.33          | 0.01 |
| FR-22                                                | B     | 1706 | 0.21  | 0.62 | 0.72 | 3.24        | 0.91         | 3.46         | 0.29          | 0.74 |

\* S = Surface

B = Bottom

Table P-7 Summary Percentiles for Dissolved Oxygen (mg/l) for August 30, 1999 through September 13, 1999

| August 31 - September 13, 1999<br>(Julian Days 242 - 255) |        |               |            |               |               |            |               |               |            |               |
|-----------------------------------------------------------|--------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                                  | Depth* | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                           |        | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                                     | S      | 31            | 38         | 58            | 45            | 48         | 50            | 1.4           | 1.0        | -0.8          |
| FR-02                                                     | B      |               |            |               |               |            |               |               |            |               |
| FR-04                                                     | S      |               |            |               |               |            |               |               |            |               |
| FR-04                                                     | B      | 47            | 53         | 59            | 40            | 41         | 42            | -0.7          | -1.2       | -1.7          |
| FR-06                                                     | S      | 47            | 53         | 59            | 48            | 53         | 58            | 0.1           | 0.0        | -0.1          |
| FR-06                                                     | B      | 31            | 36         | 39            | 3.4           | 3.7        | 3.9           | 0.3           | 0.1        | 0.0           |
| FR-08                                                     | S      | 48            | 57         | 66            | 5.8           | 6.0        | 6.3           | 1.0           | 0.3        | -0.3          |
| FR-08                                                     | B      |               |            |               |               |            |               |               |            |               |
| FR-09                                                     | S      | 38            | 51         | 62            | 5.4           | 6.0        | 6.4           | 1.6           | 0.9        | 0.2           |
| FR-09                                                     | B      | 48            | 59         | 67            | 5.6           | 5.9        | 6.2           | 0.7           | 0.0        | -0.5          |
| MR-10                                                     | S      | 42            | 47         | 55            | 5.9           | 6.4        | 6.7           | 1.7           | 1.7        | 1.2           |
| FR-11R                                                    | B      | 52            | 6.4        | 6.8           | 5.7           | 6.1        | 6.5           | 0.5           | -0.3       | -0.3          |
| SR-14                                                     | B      | 60            | 6.6        | 6.9           | 5.9           | 6.3        | 6.6           | -0.1          | -0.3       | -0.3          |
| SR-16                                                     | B      | 68            | 7.0        | 7.1           | 6.7           | 7.0        | 7.1           | -0.2          | 0.0        | 0.0           |
| FR-21                                                     | S      | 40            | 45         | 49            | 4.5           | 5.0        | 5.6           | 0.5           | 0.5        | 0.7           |
| FR-21                                                     | B      | 30            | 3.3        | 3.6           | 3.7           | 3.8        | 4.0           | 0.7           | 0.5        | 0.4           |
| FR-22                                                     | S      | 46            | 5.4        | 6.2           | 5.3           | 5.8        | 6.2           | 0.7           | 0.4        | 0.0           |
| FR-22                                                     | B      | 31            | 3.8        | 5.3           | 3.7           | 4.1        | 4.7           | 0.6           | 0.3        | -0.6          |

\* S = Surface  
B = Bottom

Table P-8 Summary Statistics for Dissolved Oxygen (mg/l) for August 30, 1999 through September 13, 1999

| August 31 - September 13, 1999<br>(Julian Days 242 - 255) |       |      |       |      |      |             |              |              |               |      |
|-----------------------------------------------------------|-------|------|-------|------|------|-------------|--------------|--------------|---------------|------|
| Station                                                   | Depth | N    | ME    | AME  | RMS  | Mean<br>Obs | StDev<br>Obs | Mean<br>Pred | StDev<br>Pred | R^2  |
| FR-02                                                     | S     | 873  | 0.62  | 1.08 | 1.24 | 4.14        | 1.02         | 4.76         | 0.15          | 0.06 |
| FR-02                                                     | B     |      |       |      |      |             |              |              |               |      |
| FR-04                                                     | S     |      |       |      |      |             |              |              |               |      |
| FR-04                                                     | B     | 1193 | -1.21 | 1.21 | 1.28 | 5.29        | 0.44         | 4.09         | 0.08          | 0.08 |
| FR-06                                                     | S     | 3737 | -0.06 | 0.44 | 0.54 | 5.32        | 0.49         | 5.26         | 0.37          | 0.07 |
| FR-06                                                     | B     | 4286 | 0.13  | 0.22 | 0.28 | 3.57        | 0.32         | 3.70         | 0.21          | 0.39 |
| FR-08                                                     | S     | 1125 | 0.31  | 0.59 | 0.70 | 5.73        | 0.74         | 6.04         | 0.22          | 0.37 |
| FR-08                                                     | B     |      |       |      |      |             |              |              |               |      |
| FR-09                                                     | S     | 4286 | 0.93  | 0.99 | 1.13 | 5.01        | 0.86         | 5.94         | 0.35          | 0.50 |
| FR-09                                                     | B     | 489  | -0.01 | 0.47 | 0.55 | 5.88        | 0.67         | 5.87         | 0.27          | 0.37 |
| MR-10                                                     | S     | 4030 | 1.59  | 1.59 | 1.64 | 4.80        | 0.47         | 6.38         | 0.28          | 0.22 |
| FR-11R                                                    | B     | 4234 | -0.16 | 0.55 | 0.70 | 6.23        | 0.71         | 6.08         | 0.32          | 0.09 |
| SR-14                                                     | B     | 3406 | -0.31 | 0.49 | 0.59 | 6.54        | 0.34         | 6.24         | 0.26          | 0.15 |
| FR-21                                                     | S     | 3816 | 0.54  | 0.65 | 0.76 | 4.49        | 0.35         | 5.03         | 0.41          | 0.00 |
| FR-21                                                     | B     | 1391 | 0.53  | 0.54 | 0.60 | 3.30        | 0.26         | 3.83         | 0.12          | 0.00 |
| FR-22                                                     | S     | 4286 | 0.32  | 0.48 | 0.58 | 5.44        | 0.63         | 5.76         | 0.30          | 0.46 |
| FR-22                                                     | B     | 4222 | 0.09  | 0.56 | 0.69 | 4.04        | 0.85         | 4.13         | 0.37          | 0.38 |

\* S = Surface  
B = Bottom

Table P-9 Summary Percentiles for Dissolved Oxygen (mg/l) for September 13, 1999 through September 28, 1999

| September 14 - September 28, 1999<br>(Julian Days 256 - 270) |        |               |            |               |               |            |               |               |            |               |
|--------------------------------------------------------------|--------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                                     | Depth* | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                              |        | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                                        | S      | 3.8           | 5.1        | 5.9           | 4.7           | 4.9        | 5.3           | 0.9           | -0.2       | -0.6          |
| FR-02                                                        | B      | 4.4           | 5.0        | 5.5           | 4.0           | 4.1        | 4.2           | -0.4          | -0.9       | -1.3          |
| FR-04                                                        | S      | 3.7           | 4.2        | 4.9           | 4.5           | 4.7        | 5.0           | 0.8           | 0.5        | 0.1           |
| FR-04                                                        | B      | 3.5           | 3.8        | 4.0           | 3.5           | 3.7        | 3.9           | 0.0           | -0.1       | -0.1          |
| FR-06                                                        | S      | 3.9           | 4.2        | 4.5           | 4.6           | 5.2        | 5.5           | 0.7           | 1.0        | 1.0           |
| FR-08                                                        | B      |               |            |               |               |            |               |               |            |               |
| FR-08                                                        | S      | 4.3           | 5.2        | 6.8           | 5.3           | 5.6        | 6.2           | 1.0           | 0.4        | -0.6          |
| FR-08                                                        | B      |               |            |               |               |            |               |               |            |               |
| FR-09                                                        | S      |               |            |               |               |            |               |               |            |               |
| FR-09                                                        | B      | 3.8           | 5.7        | 6.8           | 4.0           | 4.8        | 5.7           | 0.2           | -0.9       | -1.1          |
| MR-10                                                        | S      | 5.3           | 5.9        | 6.3           | 5.8           | 6.4        | 6.8           | 0.5           | 0.5        | 0.5           |
| FR-11R                                                       | B      | 4.7           | 6.1        | 7.0           | 4.8           | 5.7        | 6.5           | 0.1           | -0.4       | -0.5          |
| SR-14                                                        | B      | 6.2           | 6.5        | 6.6           | 6.0           | 6.4        | 6.7           | -0.2          | -0.1       | 0.1           |
| SR-16                                                        | B      | 7.1           | 7.3        | 7.5           | 7.0           | 7.2        | 7.4           | -0.2          | -0.1       | -0.1          |
| FR-21                                                        | S      | 4.4           | 4.8        | 5.4           | 4.6           | 5.1        | 5.4           | 0.2           | 0.3        | 0.0           |
| FR-21                                                        | B      | 4.0           | 4.2        | 4.6           | 3.5           | 3.8        | 4.2           | -0.5          | -0.4       | -0.4          |
| FR-22                                                        | S      | 4.2           | 5.1        | 5.8           | 5.3           | 5.6        | 6.0           | 1.1           | 0.5        | 0.2           |
| FR-22                                                        | B      | 3.6           | 3.8        | 4.4           | 3.7           | 3.9        | 4.3           | 0.1           | 0.1        | -0.1          |

\* S = Surface  
B = Bottom

Table P-10 Summary Statistics for Dissolved Oxygen (mg/l) for September 13, 1999 through September 28, 1999

| September 14 - September 28, 1999<br>(Julian Days 256 - 270) |       |      |       |      |      |          |           |           |            |      |
|--------------------------------------------------------------|-------|------|-------|------|------|----------|-----------|-----------|------------|------|
| Station                                                      | Depth | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R^2  |
| FR-02                                                        | S     | 1706 | 0.04  | 0.70 | 0.82 | 4.93     | 0.83      | 4.97      | 0.21       | 0.02 |
| FR-02                                                        | B     | 362  | -0.84 | 0.86 | 0.93 | 4.95     | 0.42      | 4.11      | 0.07       | 0.08 |
| FR-04                                                        | S     | 2328 | 0.53  | 0.66 | 0.75 | 4.23     | 0.48      | 4.75      | 0.18       | 0.02 |
| FR-04                                                        | B     | 4286 | -0.02 | 0.22 | 0.28 | 3.75     | 0.22      | 3.73      | 0.17       | 0.00 |
| FR-06                                                        | S     | 2279 | 0.88  | 0.88 | 0.92 | 4.23     | 0.23      | 5.10      | 0.32       | 0.34 |
| FR-06                                                        | B     |      |       |      |      |          |           |           |            |      |
| FR-08                                                        | S     | 2284 | 0.19  | 0.75 | 0.86 | 5.48     | 0.97      | 5.67      | 0.32       | 0.30 |
| FR-08                                                        | B     |      |       |      |      |          |           |           |            |      |
| FR-09                                                        | S     |      |       |      |      |          |           |           |            |      |
| FR-09                                                        | B     | 3645 | -0.56 | 0.77 | 0.97 | 5.38     | 1.17      | 4.82      | 0.65       | 0.59 |
| MR-10                                                        | S     | 4259 | 0.48  | 0.52 | 0.62 | 5.85     | 0.38      | 6.34      | 0.37       | 0.25 |
| FR-11R                                                       | B     | 2338 | -0.26 | 0.76 | 0.95 | 5.98     | 0.93      | 5.71      | 0.68       | 0.16 |
| SR-14                                                        | B     | 1827 | -0.13 | 0.23 | 0.30 | 6.47     | 0.15      | 6.34      | 0.24       | 0.02 |
| FR-21                                                        | S     | 4293 | 0.23  | 0.36 | 0.43 | 4.87     | 0.38      | 5.10      | 0.28       | 0.18 |
| FR-21                                                        | B     | 1269 | -0.49 | 0.50 | 0.60 | 4.27     | 0.20      | 3.78      | 0.25       | 0.01 |
| FR-22                                                        | S     | 4293 | 0.56  | 0.61 | 0.74 | 5.04     | 0.61      | 5.60      | 0.26       | 0.43 |
| FR-22                                                        | B     | 1531 | -0.01 | 0.23 | 0.36 | 3.95     | 0.46      | 3.94      | 0.27       | 0.38 |

\* S = Surface  
B = Bottom

Table P-11 Summary Percentiles for Dissolved Oxygen (mg/l) for September 28, 1999 through October 13, 1999

| September 28 - October 13, 1999<br>(Julian Days 271-285) |        |               |            |               |               |            |               |               |            |               |
|----------------------------------------------------------|--------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                                 | Depth* | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                          |        | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                                    | S      | 4.7           | 4.7        | 4.6           | 4.6           | 4.6        | 4.6           | -0.1          | -0.1       | -0.1          |
| FR-02                                                    | B      |               |            |               |               |            |               |               |            |               |
| FR-04                                                    | S      | 4.7           | 4.7        | 4.7           | 4.6           | 4.6        | 4.6           | -0.1          | -0.1       | -0.1          |
| FR-04                                                    | B      | 4.3           | 4.3        | 4.3           | 4.2           | 4.2        | 4.2           | -0.1          | -0.1       | -0.1          |
| FR-06                                                    | S      | 5.2           | 5.2        | 5.3           | 4.7           | 4.9        | 5.0           | -0.5          | -0.3       | -0.3          |
| FR-06                                                    | B      | 3.8           | 3.8        | 3.9           | 3.7           | 3.8        | 3.8           | -0.1          | -0.1       | -0.1          |
| FR-08                                                    | S      | 5.6           | 5.7        | 5.7           | 5.4           | 5.5        | 5.6           | -0.2          | -0.2       | -0.2          |
| FR-08                                                    | B      |               |            |               |               |            |               |               |            |               |
| FR-09                                                    | S      |               |            |               |               |            |               |               |            |               |
| FR-09                                                    | B      | 5.0           | 5.1        | 5.2           | 4.6           | 4.7        | 4.7           | -0.4          | -0.5       | -0.4          |
| MR-10                                                    | S      | 6.2           | 6.2        | 6.3           | 5.9           | 6.0        | 6.1           | -0.3          | -0.2       | -0.2          |
| FR-11R                                                   | B      | 5.8           | 5.9        | 6.0           | 5.3           | 5.5        | 5.6           | -0.5          | -0.4       | -0.4          |
| SR-14                                                    | B      | 6.2           | 6.3        | 6.3           | 5.1           | 6.1        | 6.2           | -0.1          | -0.1       | -0.1          |
| SR-16                                                    | B      | 7.1           | 7.2        | 7.2           | 7.1           | 7.1        | 7.1           | -0.1          | -0.1       | 0.0           |
| FR-21                                                    | S      | 4.7           | 4.9        | 5.0           | 4.5           | 4.6        | 4.6           | -0.2          | -0.3       | -0.4          |
| FR-21                                                    | B      | 3.9           | 4.0        | 4.0           | 3.6           | 3.8        | 3.9           | -0.2          | -0.1       | -0.1          |
| FR-22                                                    | S      | 5.6           | 5.6        | 5.7           | 5.4           | 5.5        | 5.5           | -0.2          | -0.1       | -0.1          |
| FR-22                                                    | B      | 4.2           | 4.2        | 4.2           | 4.1           | 4.1        | 4.1           | -0.1          | -0.1       | -0.1          |

\* S = Surface  
B = Bottom

Table P-12 Summary Statistics for Dissolved Oxygen (mg/l) for September 28, 1999 through October 13, 1999

| September 28 - October 13, 1999<br>(Julian Days 271-285) |       |      |      |      |      |          |           |           |            |                |
|----------------------------------------------------------|-------|------|------|------|------|----------|-----------|-----------|------------|----------------|
| Station                                                  | Depth | N    | ME   | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-02                                                    | S     | 2871 | 4.79 | 4.81 | 4.84 | 4.90     | 4.93      | 4.85      | 4.87       | 4.96           |
| FR-02                                                    | B     |      |      |      |      |          |           |           |            |                |
| FR-04                                                    | S     | 1284 | 4.74 | 4.76 | 4.78 | 4.87     | 4.94      | 4.80      | 4.83       | 4.98           |
| FR-04                                                    | B     | 1292 | 4.33 | 4.34 | 4.36 | 4.40     | 4.42      | 4.36      | 4.38       | 4.43           |
| FR-06                                                    | S     | 2577 | 5.31 | 5.34 | 5.37 | 5.46     | 5.50      | 5.40      | 5.43       | 5.55           |
| FR-06                                                    | B     | 2516 | 3.88 | 3.90 | 3.92 | 3.97     | 3.99      | 3.94      | 3.95       | 4.01           |
| FR-08                                                    | S     | 2620 | 5.75 | 5.78 | 5.81 | 5.97     | 6.04      | 5.86      | 5.91       | 6.08           |
| FR-08                                                    | B     |      |      |      |      |          |           |           |            |                |
| FR-09                                                    | S     |      |      |      |      |          |           |           |            |                |
| FR-09                                                    | B     | 3336 | 5.22 | 5.29 | 5.36 | 5.57     | 5.65      | 5.43      | 5.50       | 5.76           |
| MR-10                                                    | S     | 2127 | 6.39 | 6.45 | 6.52 | 6.71     | 6.75      | 6.59      | 6.66       | 6.79           |
| FR-11R                                                   | B     | 2514 | 6.06 | 6.12 | 6.18 | 6.35     | 6.38      | 6.25      | 6.30       | 6.41           |
| SR-14                                                    | B     | 2234 | 6.34 | 6.37 | 6.40 | 6.47     | 6.49      | 6.42      | 6.45       | 6.51           |
| FR-21                                                    | S     | 3138 | 5.04 | 5.07 | 5.12 | 5.24     | 5.28      | 5.17      | 5.21       | 5.31           |
| FR-21                                                    | B     | 3352 | 3.98 | 4.00 | 4.02 | 4.07     | 4.08      | 4.03      | 4.05       | 4.10           |
| FR-22                                                    | S     | 2561 | 5.68 | 5.71 | 5.75 | 5.88     | 5.93      | 5.79      | 5.83       | 5.99           |
| FR-22                                                    | B     | 1498 | 4.27 | 4.28 | 4.30 | 4.41     | 4.45      | 4.32      | 4.37       | 4.48           |

\* S = Surface  
B = Bottom

**APPENDIX Q 1997 DISSOLVED OXYGEN**





Table Q-1 Summary Percentiles for Dissolved Oxygen (mg/l) for July 10 through October 6, 1997

| July 10 - October 6, 1997<br>[Julian Days 191-279] |                    |               |            |               |               |            |               |               |               |
|----------------------------------------------------|--------------------|---------------|------------|---------------|---------------|------------|---------------|---------------|---------------|
| Stations                                           | Depth <sup>*</sup> | Measured      |            |               | Simulated     |            |               | Difference    |               |
|                                                    |                    | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 90%<br>(mg/L) |
| FR-02                                              | S                  | 42            | 49         | 58            | 44            | 49         | 57            | 0.3           | -0.2          |
| FR-02                                              | B                  | 39            | 48         | 57            | 42            | 46         | 49            | 0.3           | -0.8          |
| FR-04                                              | S                  | 34            | 51         | 61            | 42            | 48         | 54            | 0.7           | -0.7          |
| FR-04                                              | B                  | 34            | 41         | 45            | 36            | 40         | 43            | 0.2           | -0.2          |
| FR-06                                              | S                  | 39            | 49         | 62            | 49            | 56         | 61            | 1.0           | -0.1          |
| FR-06                                              | B                  | 34            | 39         | 46            | 34            | 37         | 43            | 0.1           | -0.3          |
| FR-08                                              | S                  | 49            | 61         | 70            | 55            | 61         | 66            | 0.6           | -0.4          |
| FR-08                                              | B                  | 35            | 51         | 70            | 39            | 51         | 62            | 0.4           | -0.9          |
| FR-09                                              | B                  | 43            | 59         | 71            | 45            | 57         | 68            | 0.2           | -0.3          |
| MR-10                                              | B                  | 50            | 59         | 67            | 51            | 56         | 61            | 0.1           | -0.6          |
| FR-11                                              | B                  | 60            | 66         | 72            | 61            | 65         | 70            | 0.1           | -0.3          |
| SR-14                                              | B                  | 67            | 74         | 81            | 63            | 69         | 77            | -0.4          | -0.4          |

\* S = Surface

B = Bottom

Table Q-2 Summary Statistics for Dissolved Oxygen (mg/l) for July 10 through October 6, 1997

| July 10 - October 6, 1999<br>[Julian Days 191-279] |       |       |       |      |      |          |           |           |            |      |
|----------------------------------------------------|-------|-------|-------|------|------|----------|-----------|-----------|------------|------|
| Station                                            | Depth | N     | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R^2  |
| FR-02                                              | S     | 5573  | 0.05  | 0.50 | 0.65 | 4.95     | 0.71      | 5.00      | 0.45       | 0.21 |
| FR-02                                              | B     | 5437  | -0.24 | 0.51 | 0.66 | 4.80     | 0.73      | 4.56      | 0.29       | 0.31 |
| FR-04                                              | S     | 5925  | -0.15 | 0.64 | 0.80 | 4.93     | 0.94      | 4.78      | 0.46       | 0.30 |
| FR-04                                              | B     | 6316  | -0.04 | 0.35 | 0.44 | 4.02     | 0.42      | 3.97      | 0.26       | 0.06 |
| FR-06                                              | S     | 10029 | 0.58  | 0.87 | 1.04 | 4.95     | 0.96      | 5.53      | 0.47       | 0.19 |
| FR-06                                              | B     | 6905  | -0.15 | 0.40 | 0.50 | 3.95     | 0.49      | 3.81      | 0.37       | 0.15 |
| FR-08                                              | S     | 10716 | 0.07  | 0.45 | 0.55 | 5.98     | 0.81      | 6.05      | 0.43       | 0.61 |
| FR-08                                              | B     | 10390 | -0.08 | 1.11 | 1.38 | 5.15     | 1.37      | 5.08      | 0.84       | 0.09 |
| FR-09                                              | B     | 6570  | -0.12 | 0.48 | 0.61 | 5.81     | 1.04      | 5.69      | 0.80       | 0.67 |
| MR-10                                              | B     | 8880  | -0.35 | 0.61 | 0.74 | 5.87     | 0.66      | 5.52      | 0.39       | 0.09 |
| FR-11                                              | B     | 6446  | -0.07 | 0.33 | 0.46 | 6.59     | 0.49      | 6.52      | 0.38       | 0.24 |
| SR-14                                              | B     | 10374 | -0.45 | 0.47 | 0.58 | 7.41     | 0.54      | 6.97      | 0.51       | 0.57 |

\* S = Surface

B = Bottom

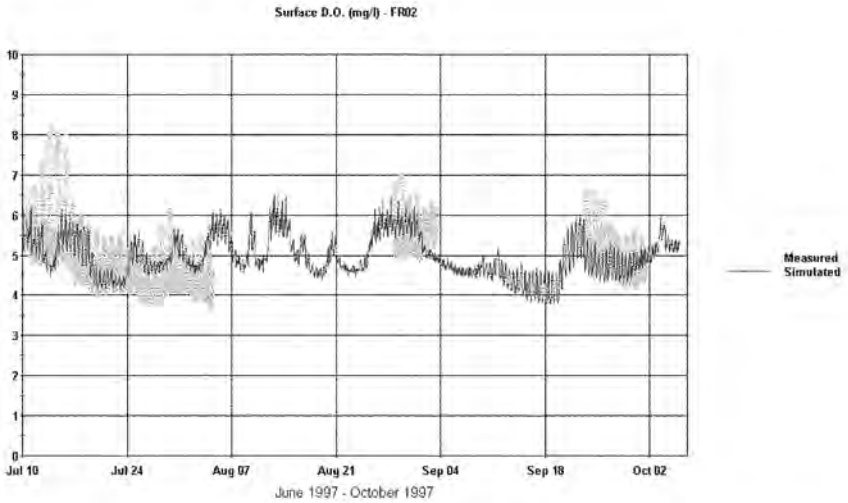


Figure Q-1 Dissolved Oxygen Calibration at FR-02 (Surface) for July 10 through October 6, 1997

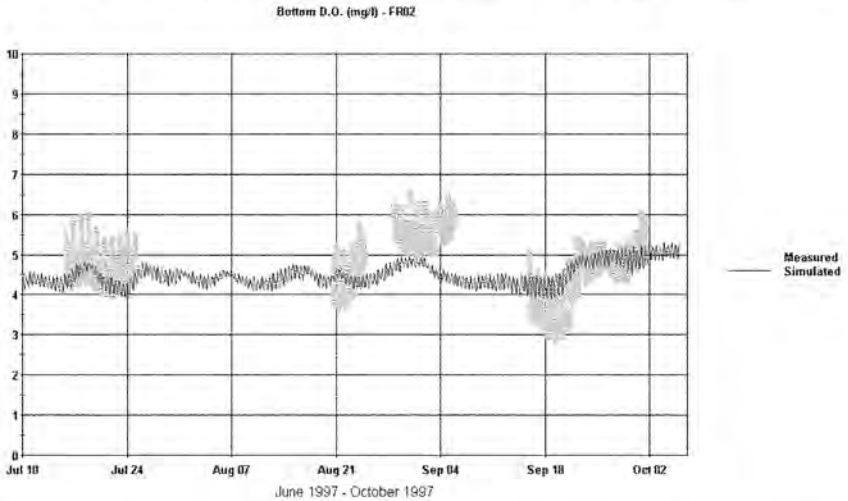


Figure Q-2 Dissolved Oxygen Calibration at FR-02 (Bottom) for July 10 through October 6, 1997

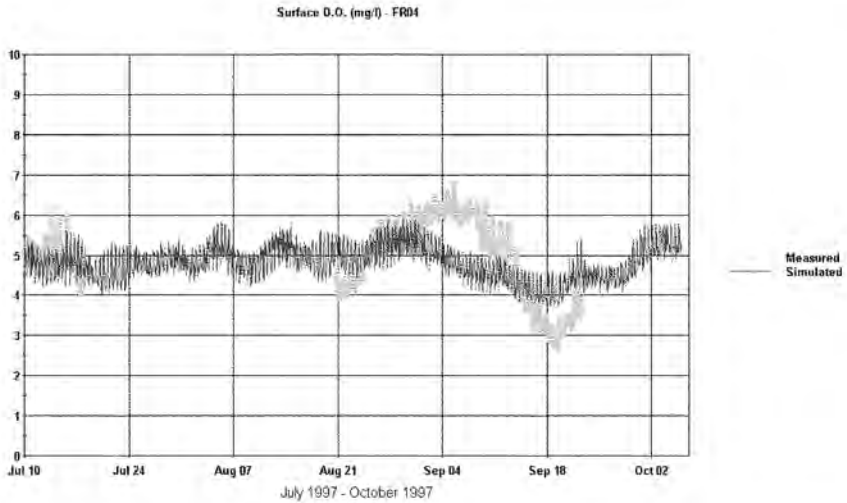


Figure Q-3 Dissolved Oxygen Calibration at FR-04 (Surface) for July 10 through October 6, 1997

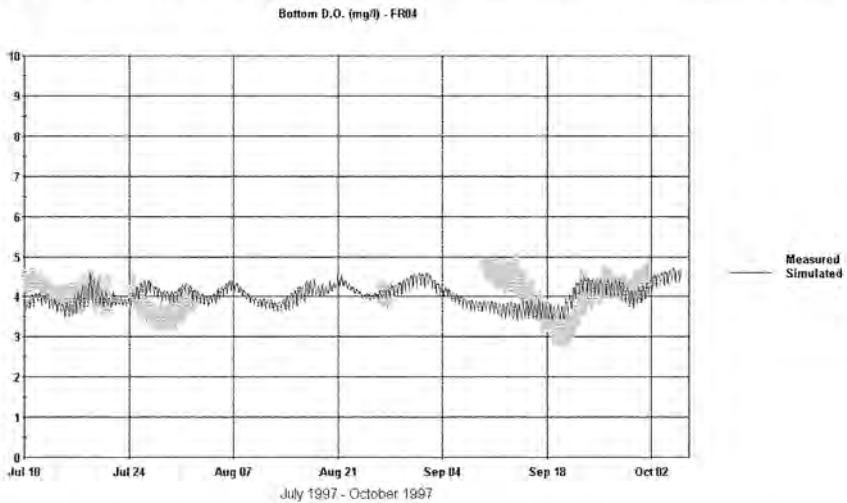


Figure Q-4 Dissolved Oxygen Calibration at FR-04 (Bottom) for July 10 through October 6, 1997

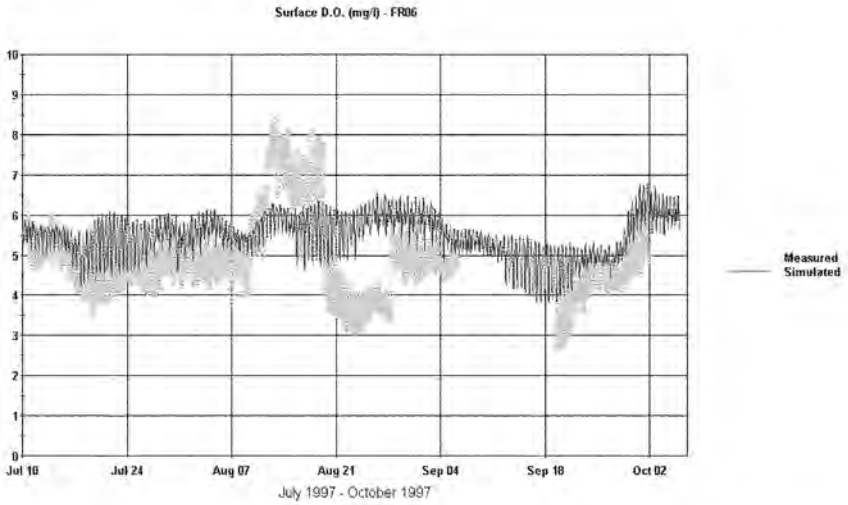


Figure Q-5 Dissolved Oxygen Calibration at FR-06 (Surface) for July 10 through October 6, 1997

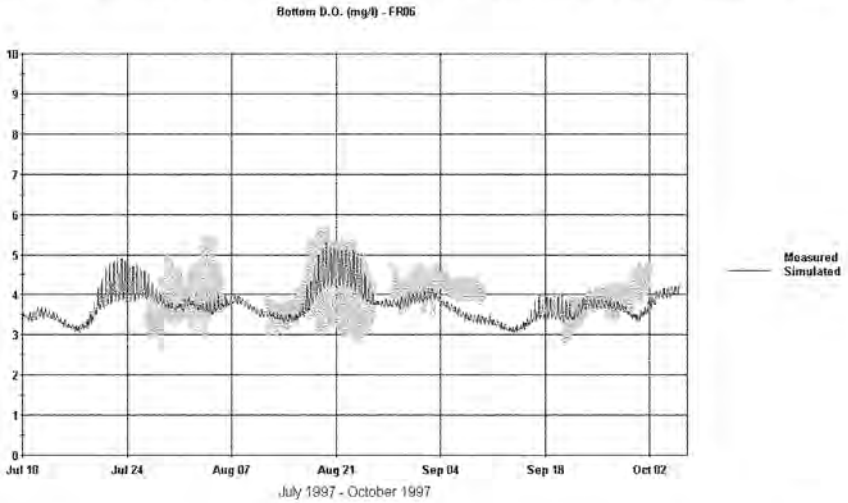


Figure Q-6 Dissolved Oxygen Calibration at FR-06 (Bottom) for July 10 through October 6, 1997

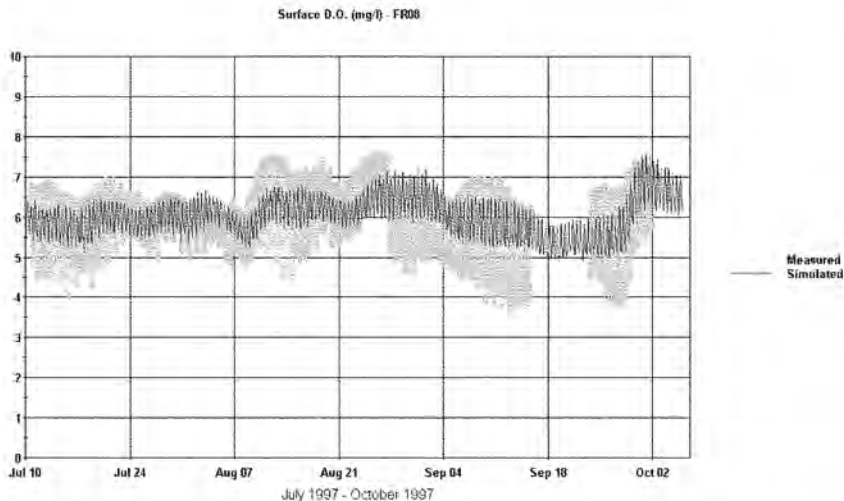


Figure Q-7 Dissolved Oxygen Calibration at FR-08 (Surface) for July 10 through October 6, 1997

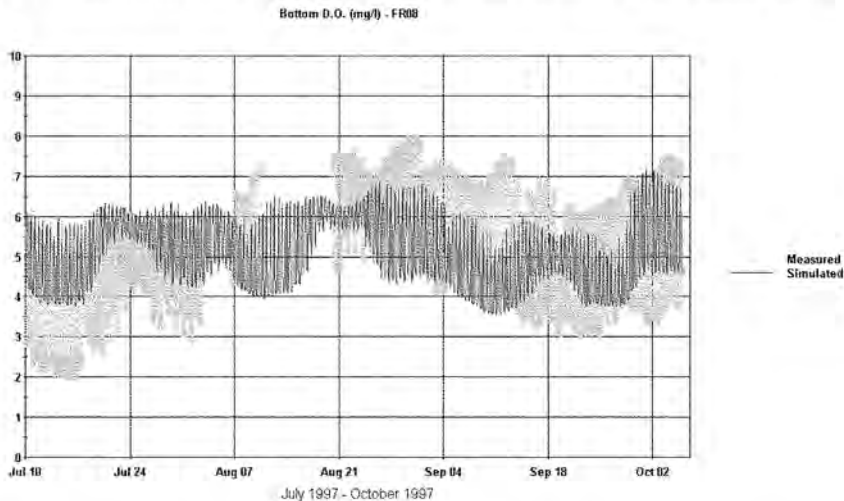


Figure Q-8 Dissolved Oxygen Calibration at FR-08 (Bottom) for July 10 through October 6, 1997

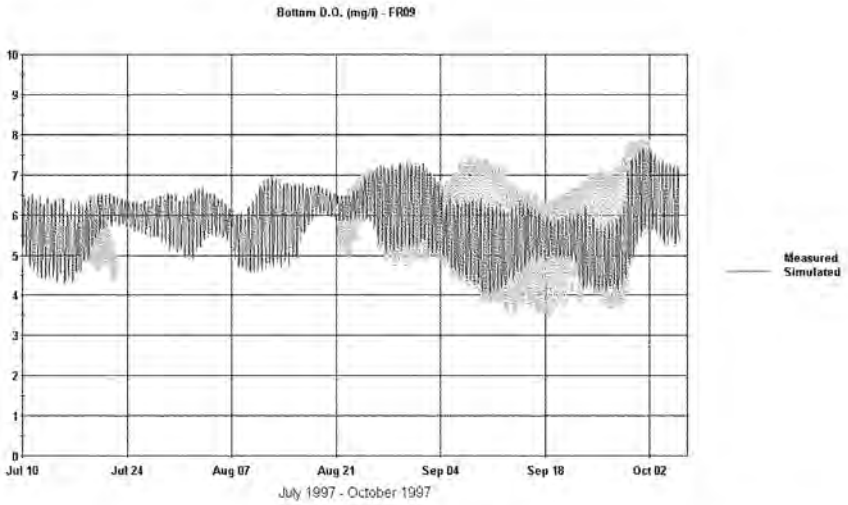


Figure Q-9 Dissolved Oxygen Calibration at FR-09 (Bottom) for July 10 through October 6, 1997

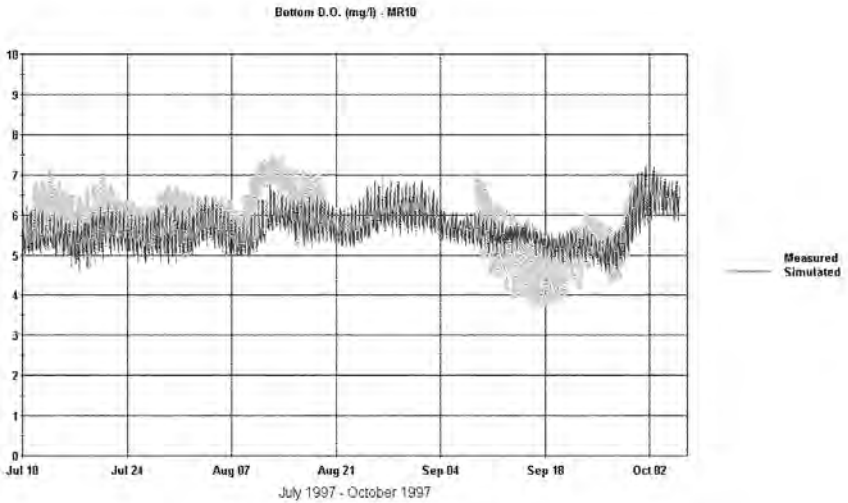


Figure Q-10 Dissolved Oxygen Calibration at FR-11 (Bottom) for July 10 through October 6, 1997

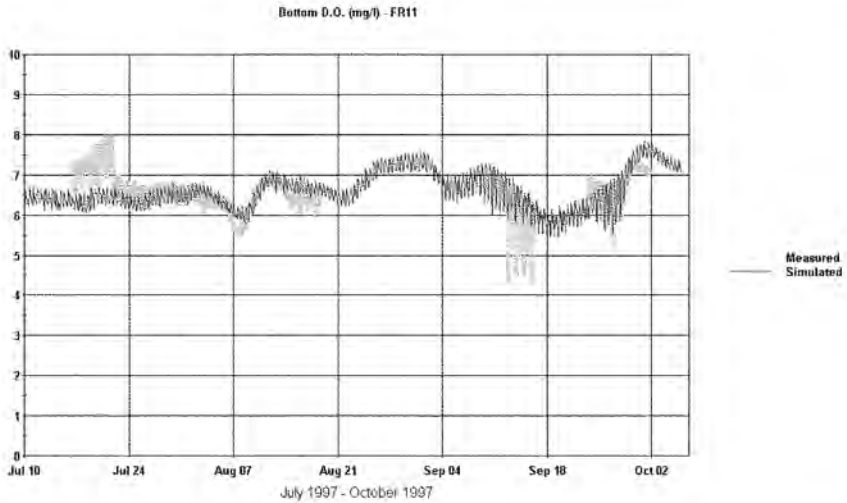


Figure Q-11 Dissolved Oxygen Calibration at MR-10 (Bottom) for July 10 through October 6, 1997

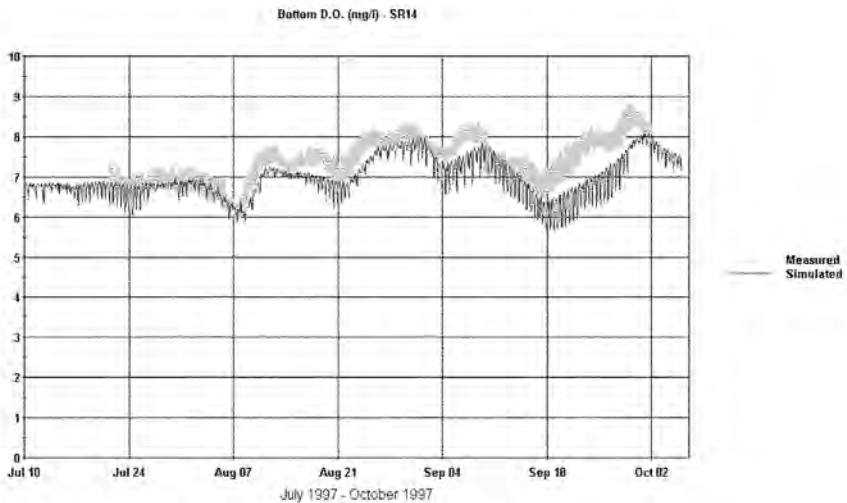


Figure Q-12 Dissolved Oxygen Calibration at SR-14 (Bottom) for July 10 through October 6, 1997

Table Q-1 Summary Percentiles for Dissolved Oxygen (mg/l) for July 10 through July 23, 1997

| July 10 - July 23, 1997<br>[Julian Days 191-204] |        |               |            |               |               |            |               |               |            |               |
|--------------------------------------------------|--------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                         | Depth* | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                  |        | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                            | S      | 4.4           | 5.1        | 6.2           | 4.3           | 5.0        | 5.6           | -0.1          | 0.0        | -0.6          |
| FR-02                                            | B      | 4.2           | 4.6        | 5.5           | 4.2           | 4.5        | 4.7           | 0.0           | -0.1       | -0.7          |
| FR-04                                            | S      | 4.6           | 5.0        | 5.4           | 4.4           | 4.8        | 5.2           | -0.2          | -0.2       | -0.2          |
| FR-04                                            | B      | 3.8           | 4.1        | 4.5           | 3.7           | 3.9        | 4.2           | -0.1          | -0.2       | -0.3          |
| FR-06                                            | S      | 4.1           | 5.0        | 5.5           | 4.8           | 5.4        | 5.8           | 0.7           | 0.5        | 0.2           |
| FR-06                                            | B      |               |            |               |               |            |               |               |            |               |
| FR-08                                            | S      | 4.9           | 6.1        | 6.7           | 5.5           | 5.9        | 6.3           | 0.6           | -0.1       | -0.4          |
| FR-08                                            | B      | 2.3           | 3.7        | 5.3           | 3.9           | 5.1        | 6.0           | 1.6           | 1.4        | 0.6           |
| FR-09                                            | B      | 4.9           | 5.3        | 5.8           | 5.3           | 6.0        | 6.4           | 0.4           | 0.7        | 0.7           |
| MR-10                                            | B      | 5.5           | 6.1        | 6.6           | 5.1           | 5.4        | 5.9           | -0.4          | -0.6       | -0.6          |
| FR-11                                            | B      | 6.7           | 7.3        | 7.7           | 6.2           | 6.4        | 6.6           | -0.5          | -0.6       | -1.1          |
| SR-14                                            | B      | 6.8           | 6.9        | 7.1           | 6.3           | 6.8        | 6.8           | -0.4          | -0.2       | -0.3          |

\* S = Surface  
B = Bottom

Table Q-2 Summary Statistics for Dissolved Oxygen (mg/l) for July 10 through July 23, 1997

| July 10 - July 23, 1997<br>[Julian Days 191-204] |       |      |       |      |      |             |              |              |               |                |
|--------------------------------------------------|-------|------|-------|------|------|-------------|--------------|--------------|---------------|----------------|
| Station                                          | Depth | N    | ME    | AME  | RMS  | Mean<br>Obs | StDev<br>Obs | Mean<br>Pred | StDev<br>Pred | R <sup>2</sup> |
| FR-02                                            | S     | 1795 | -0.19 | 0.50 | 0.73 | 5.19        | 0.79         | 5.00         | 0.50          | 0.23           |
| FR-02                                            | B     | 1040 | -0.26 | 0.37 | 0.51 | 4.71        | 0.52         | 4.45         | 0.21          | 0.30           |
| FR-04                                            | S     | 1134 | -0.17 | 0.37 | 0.48 | 5.00        | 0.34         | 4.84         | 0.28          | 0.00           |
| FR-04                                            | B     | 1634 | -0.20 | 0.25 | 0.29 | 4.12        | 0.24         | 3.93         | 0.19          | 0.31           |
| FR-06                                            | S     | 1783 | 0.46  | 0.53 | 0.62 | 4.90        | 0.53         | 5.36         | 0.38          | 0.39           |
| FR-06                                            | B     |      |       |      |      |             |              |              |               |                |
| FR-08                                            | S     | 1738 | -0.03 | 0.40 | 0.47 | 5.91        | 0.70         | 5.88         | 0.30          | 0.75           |
| FR-08                                            | B     | 1730 | 1.23  | 1.26 | 1.42 | 3.76        | 1.15         | 4.99         | 0.83          | 0.63           |
| FR-09                                            | B     | 668  | 0.64  | 0.69 | 0.77 | 5.30        | 0.35         | 5.94         | 0.45          | 0.23           |
| MR-10                                            | B     | 1661 | -0.57 | 0.67 | 0.80 | 6.05        | 0.41         | 5.48         | 0.31          | 0.04           |
| FR-11                                            | B     | 924  | -0.85 | 0.85 | 0.91 | 7.24        | 0.37         | 6.39         | 0.16          | 0.24           |
| SR-14                                            | B     | 210  | -0.27 | 0.28 | 0.33 | 6.92        | 0.15         | 6.65         | 0.20          | 0.15           |

\* S = Surface  
B = Bottom



Table Q-3 Summary Percentiles for Dissolved Oxygen (mg/l) for July 24 through August 7, 1997

| July 24 - August 7, 1997<br>[Julian Days 205 -219] |                    |               |            |               |               |            |               |               |               |
|----------------------------------------------------|--------------------|---------------|------------|---------------|---------------|------------|---------------|---------------|---------------|
| Stations                                           | Depth <sup>a</sup> | Measured      |            |               | Simulated     |            |               | Difference    |               |
|                                                    |                    | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 90%<br>(mg/L) |
| FR-02                                              | S                  | 3.9           | 4.3        | 5.0           | 4.6           | 4.9        | 5.4           | 0.7           | 0.5           |
| FR-02                                              | B                  | 4.4           | 4.8        | 5.4           | 4.0           | 4.3        | 4.5           | -0.3          | -0.9          |
| FR-04                                              | S                  |               |            |               |               |            |               |               |               |
| FR-04                                              | B                  | 3.4           | 3.6        | 4.1           | 4.0           | 4.1        | 4.3           | 0.5           | 0.2           |
| FR-06                                              | S                  | 4.4           | 4.9        | 5.4           | 5.1           | 5.6        | 5.9           | 0.7           | 0.5           |
| FR-06                                              | B                  | 3.3           | 3.8        | 4.6           | 3.6           | 3.7        | 4.0           | 0.3           | -0.7          |
| FR-08                                              | S                  | 5.3           | 6.0        | 6.4           | 5.7           | 6.0        | 6.4           | 0.3           | -0.1          |
| FR-08                                              | B                  | 3.7           | 5.1        | 5.8           | 4.5           | 5.5        | 6.1           | 0.8           | 0.3           |
| FR-09                                              | B                  |               |            |               |               |            |               |               |               |
| MR-10                                              | B                  | 5.7           | 6.0        | 6.4           | 5.1           | 5.5        | 6.0           | -0.6          | -0.3          |
| FR-11                                              | B                  | 6.3           | 6.5        | 6.7           | 6.2           | 6.4        | 6.7           | -0.1          | -0.1          |
| SR-14                                              | B                  | 6.5           | 6.9        | 7.1           | 6.4           | 6.8        | 6.9           | -0.1          | -0.2          |

<sup>a</sup> S = Surface  
B = Bottom

Table Q-4 Summary Statistics for Dissolved Oxygen (mg/l) for July 24 through August 7, 1997

| July 24 - August 7, 1997<br>[Julian Days 205 -219] |       |      |       |      |      |             |              |              |               |                |
|----------------------------------------------------|-------|------|-------|------|------|-------------|--------------|--------------|---------------|----------------|
| Station                                            | Depth | N    | ME    | AME  | RMS  | Mean<br>Obs | StDev<br>Obs | Mean<br>Pred | StDev<br>Pred | R <sup>2</sup> |
| FR-02                                              | S     | 1654 | 0.56  | 0.63 | 0.71 | 4.40        | 0.42         | 4.96         | 0.30          | 0.07           |
| FR-02                                              | B     | 175  | -0.56 | 0.56 | 0.63 | 4.82        | 0.38         | 4.26         | 0.17          | 0.45           |
| FR-04                                              | S     |      |       |      |      |             |              |              |               |                |
| FR-04                                              | B     | 1292 | 0.36  | 0.39 | 0.45 | 3.76        | 0.27         | 4.13         | 0.13          | 0.05           |
| FR-06                                              | S     | 2010 | 0.64  | 0.64 | 0.70 | 4.90        | 0.38         | 5.54         | 0.32          | 0.44           |
| FR-06                                              | B     | 1469 | -0.11 | 0.45 | 0.58 | 3.87        | 0.53         | 3.76         | 0.15          | 0.02           |
| FR-08                                              | S     | 2005 | 0.10  | 0.24 | 0.30 | 5.91        | 0.41         | 6.01         | 0.27          | 0.55           |
| FR-08                                              | B     | 1452 | 0.50  | 0.74 | 0.92 | 4.92        | 0.78         | 5.42         | 0.59          | 0.16           |
| FR-09                                              | B     |      |       |      |      |             |              |              |               |                |
| MR-10                                              | B     | 2003 | -0.46 | 0.56 | 0.69 | 6.01        | 0.28         | 5.55         | 0.35          | 0.09           |
| FR-11                                              | B     | 2015 | -0.07 | 0.18 | 0.21 | 6.49        | 0.20         | 6.42         | 0.17          | 0.18           |
| SR-14                                              | B     | 2012 | -0.14 | 0.18 | 0.22 | 6.82        | 0.22         | 6.68         | 0.20          | 0.43           |

<sup>a</sup> S = Surface  
B = Bottom

Table Q-5 Summary Percentiles for Dissolved Oxygen (mg/l) for August 8 through August 22, 1997

| August 8 - August 22, 1997<br>[Julian Days 220-234] |        |               |            |               |               |            |               |            |            |               |
|-----------------------------------------------------|--------|---------------|------------|---------------|---------------|------------|---------------|------------|------------|---------------|
| Stations                                            | Depth* | Measured      |            |               | Simulated     |            |               | Difference |            |               |
|                                                     |        | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10% (mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                               | S      |               |            |               |               |            |               |            |            |               |
| FR-02                                               | B      | 3.8           | 4.2        | 5.1           | 4.4           | 4.5        | 4.6           | 0.6        | 0.3        | -0.6          |
| FR-04                                               | S      |               |            |               |               |            |               |            |            |               |
| FR-04                                               | B      |               |            |               |               |            |               |            |            |               |
| FR-06                                               | S      | 4.1           | 6.2        | 7.7           | 5.1           | 5.7        | 6.2           | 1.0        | -0.4       | -1.5          |
| FR-06                                               | B      | 3.3           | 3.7        | 5.1           | 3.4           | 3.6        | 4.9           | 0.1        | -0.1       | -0.2          |
| FR-08                                               | S      | 5.3           | 6.4        | 7.3           | 5.7           | 6.2        | 6.6           | 0.4        | -0.3       | -0.7          |
| FR-08                                               | B      |               |            |               |               |            |               |            |            |               |
| FR-09                                               | B      |               |            |               |               |            |               |            |            |               |
| MR-10                                               | B      | 5.6           | 6.6        | 7.1           | 5.3           | 5.8        | 6.3           | -0.6       | -0.8       | -0.8          |
| FR-11                                               | B      | 6.1           | 6.5        | 6.8           | 6.1           | 6.7        | 6.9           | 0.0        | 0.2        | 0.1           |
| SR-14                                               | B      | 6.9           | 7.4        | 7.6           | 6.4           | 7.0        | 7.1           | -0.6       | -0.4       | -0.5          |

\* S = Surface  
B = Bottom

Table Q-6 Summary Statistics for Dissolved Oxygen (mg/l) for August 8 through August 22, 1997

| August 8 - August 22, 1997<br>[Julian Days 220-234] |       |      |       |      |      |             |              |              |               |                |
|-----------------------------------------------------|-------|------|-------|------|------|-------------|--------------|--------------|---------------|----------------|
| Station                                             | Depth | N    | ME    | AME  | RMS  | Mean<br>Obs | StDev<br>Obs | Mean<br>Pred | StDev<br>Pred | R <sup>2</sup> |
| FR-02                                               | S     |      |       |      |      |             |              |              |               |                |
| FR-02                                               | B     | 214  | 0.16  | 0.41 | 0.47 | 4.33        | 0.49         | 4.49         | 0.07          | 0.58           |
| FR-04                                               | S     |      |       |      |      |             |              |              |               |                |
| FR-04                                               | B     |      |       |      |      |             |              |              |               |                |
| FR-06                                               | S     | 1989 | -0.34 | 1.02 | 1.17 | 6.03        | 1.29         | 5.69         | 0.39          | 0.32           |
| FR-06                                               | B     | 1473 | 0.01  | 0.34 | 0.44 | 3.92        | 0.62         | 3.93         | 0.57          | 0.53           |
| FR-08                                               | S     | 1965 | -0.21 | 0.45 | 0.54 | 6.36        | 0.73         | 6.16         | 0.33          | 0.65           |
| FR-08                                               | B     |      |       |      |      |             |              |              |               |                |
| FR-09                                               | B     |      |       |      |      |             |              |              |               |                |
| MR-10                                               | B     | 1649 | -0.75 | 0.81 | 0.94 | 6.54        | 0.49         | 5.79         | 0.37          | 0.03           |
| FR-11                                               | B     | 1514 | 0.12  | 0.18 | 0.21 | 6.51        | 0.28         | 6.63         | 0.30          | 0.66           |
| SR-14                                               | B     | 2013 | -0.45 | 0.46 | 0.48 | 7.30        | 0.28         | 6.85         | 0.30          | 0.72           |

\* S = Surface  
B = Bottom

Table Q-7 Summary Percentiles for Dissolved Oxygen (mg/l) for August 23 through September 6, 1997

| August 23 - September 6, 1997<br>[Julian Days 235 - 249] |        |               |            |               |               |            |               |               |            |               |
|----------------------------------------------------------|--------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                                 | Depth* | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                          |        | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                                    | S      | 5.1           | 5.4        | 6.2           | 5.0           | 5.6        | 6.0           | -0.1          | 0.1        | -0.2          |
| FR-02                                                    | B      | 4.8           | 5.5        | 6.2           | 4.3           | 4.6        | 4.9           | -0.5          | -0.9       | -1.3          |
| FR-04                                                    | S      | 4.2           | 5.2        | 5.7           | 4.7           | 5.2        | 5.6           | 0.5           | 0.0        | -0.1          |
| FR-04                                                    | B      | 3.8           | 4.1        | 4.3           | 4.0           | 4.1        | 4.2           | 0.2           | 0.1        | 0.0           |
| FR-06                                                    | S      | 3.6           | 4.7        | 5.3           | 5.4           | 5.9        | 6.3           | 1.8           | 1.2        | 1.1           |
| FR-06                                                    | B      | 3.5           | 4.1        | 4.5           | 3.7           | 3.9        | 4.2           | 0.2           | -0.2       | -0.3          |
| FR-08                                                    | S      | 5.1           | 6.3        | 7.3           | 5.9           | 6.3        | 6.9           | 0.8           | 0.0        | -0.4          |
| FR-08                                                    | B      | 4.7           | 6.6        | 7.6           | 4.5           | 5.4        | 6.5           | -0.3          | -1.2       | -1.1          |
| FR-09                                                    | B      | 5.2           | 6.6        | 7.1           | 5.2           | 6.3        | 7.1           | 0.0           | -0.3       | 0.0           |
| MR-10                                                    | B      |               |            |               |               |            |               |               |            |               |
| FR-11                                                    | B      |               |            |               |               |            |               |               |            |               |
| SR-14                                                    | B      | 7.6           | 7.9        | 8.1           | 7.0           | 7.6        | 7.8           | -0.6          | -0.3       | -0.3          |

\* S = Surface  
B = Bottom

Table Q-8 Summary Statistics for Dissolved Oxygen (mg/l) for August 23 through September 6, 1997

| August 23 - September 6, 1997<br>[Julian Days 235 - 249] |       |      |       |      |      |          |           |           |            |      |
|----------------------------------------------------------|-------|------|-------|------|------|----------|-----------|-----------|------------|------|
| Station                                                  | Depth | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R^2  |
| FR-02                                                    | S     | 835  | -0.04 | 0.52 | 0.60 | 5.55     | 0.44      | 5.51      | 0.38       | 0.00 |
| FR-02                                                    | B     | 1463 | -0.88 | 0.89 | 0.99 | 5.47     | 0.53      | 4.59      | 0.22       | 0.28 |
| FR-04                                                    | S     | 1478 | 0.16  | 0.40 | 0.52 | 5.02     | 0.60      | 5.18      | 0.31       | 0.33 |
| FR-04                                                    | B     | 275  | 0.07  | 0.14 | 0.16 | 4.05     | 0.16      | 4.12      | 0.08       | 0.19 |
| FR-06                                                    | S     | 1988 | 1.38  | 1.38 | 1.55 | 4.48     | 0.65      | 5.85      | 0.35       | 0.00 |
| FR-06                                                    | B     | 1662 | -0.14 | 0.36 | 0.45 | 4.08     | 0.40      | 3.94      | 0.26       | 0.05 |
| FR-08                                                    | S     | 1992 | 0.17  | 0.53 | 0.62 | 6.21     | 0.79      | 6.38      | 0.38       | 0.50 |
| FR-08                                                    | B     | 2009 | -0.96 | 1.28 | 1.62 | 6.37     | 1.04      | 5.41      | 0.80       | 0.00 |
| FR-09                                                    | B     | 1965 | -0.10 | 0.26 | 0.34 | 6.29     | 0.73      | 6.18      | 0.68       | 0.81 |
| MR-10                                                    | B     |      |       |      |      |          |           |           |            |      |
| FR-11                                                    | B     |      |       |      |      |          |           |           |            |      |
| SR-14                                                    | B     | 2008 | -0.38 | 0.39 | 0.45 | 7.86     | 0.20      | 7.48      | 0.32       | 0.48 |

\* S = Surface  
B = Bottom

Table Q-9 Summary Percentiles for Dissolved Oxygen (mg/l) for September 7 through September 20, 1997

| September 7 - September 20, 1997<br>[Julian Days 250-263] |        |               |            |               |               |            |               |               |            |               |
|-----------------------------------------------------------|--------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                                  | Depth* | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                           |        | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                                     | S      |               |            |               |               |            |               |               |            |               |
| FR-02                                                     | B      | 3.1           | 3.9        | 4.5           | 4.0           | 4.3        | 4.4           | 0.8           | 0.4        | 0.0           |
| FR-04                                                     | S      | 3.1           | 4.4        | 6.1           | 3.9           | 4.4        | 4.8           | 0.8           | -0.1       | -1.3          |
| FR-04                                                     | B      | 3.2           | 4.2        | 4.8           | 3.5           | 3.7        | 3.8           | 0.3           | -0.5       | -0.9          |
| FR-06                                                     | S      |               |            |               |               |            |               |               |            |               |
| FR-06                                                     | B      | 3.9           | 4.1        | 4.3           | 3.3           | 3.4        | 3.5           | -0.6          | -0.7       | -0.8          |
| FR-08                                                     | S      | 4.1           | 5.4        | 6.8           | 5.3           | 5.8        | 6.4           | 1.3           | 0.4        | -0.5          |
| FR-08                                                     | B      | 3.8           | 4.7        | 6.7           | 3.7           | 4.6        | 5.5           | -0.1          | -0.1       | -1.2          |
| FR-09                                                     | B      | 4.0           | 5.2        | 7.0           | 4.4           | 5.3        | 6.1           | 0.4           | 0.0        | -0.8          |
| MR-10                                                     | B      | 4.2           | 5.2        | 6.2           | 5.1           | 5.4        | 5.7           | 0.9           | 0.2        | -0.5          |
| FR-11                                                     | B      | 4.8           | 6.0        | 6.4           | 6.0           | 6.4        | 6.8           | 1.1           | 0.4        | 0.4           |
| SR-14                                                     | B      | 6.9           | 7.3        | 8.1           | 6.0           | 6.9        | 7.7           | -0.8          | -0.4       | -0.4          |

\* S = Surface  
B = Bottom

Table Q-10 Summary Statistics for Dissolved Oxygen (mg/l) for September 7 through September 20, 1997

| September 7 - September 20, 1997<br>[Julian Days 250-263] |       |      |       |      |      |          |           |           |            |                |
|-----------------------------------------------------------|-------|------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Station                                                   | Depth | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-02                                                     | S     |      |       |      |      |          |           |           |            |                |
| FR-02                                                     | B     | 624  | 0.42  | 0.49 | 0.58 | 3.81     | 0.53      | 4.23      | 0.18       | 0.64           |
| FR-04                                                     | S     | 1824 | -0.15 | 0.78 | 0.92 | 4.51     | 1.09      | 4.36      | 0.33       | 0.42           |
| FR-04                                                     | B     | 1483 | -0.38 | 0.57 | 0.65 | 4.06     | 0.59      | 3.68      | 0.14       | 0.35           |
| FR-06                                                     | S     |      |       |      |      |          |           |           |            |                |
| FR-06                                                     | B     | 389  | -0.70 | 0.70 | 0.71 | 4.12     | 0.16      | 3.42      | 0.07       | 0.50           |
| FR-08                                                     | S     | 1252 | 0.36  | 0.64 | 0.76 | 5.44     | 1.02      | 5.80      | 0.38       | 0.88           |
| FR-08                                                     | B     | 1814 | -0.44 | 1.03 | 1.37 | 5.00     | 1.10      | 4.56      | 0.70       | 0.00           |
| FR-09                                                     | B     | 1870 | -0.08 | 0.52 | 0.63 | 5.36     | 1.10      | 5.28      | 0.63       | 0.77           |
| MR-10                                                     | B     | 1620 | 0.19  | 0.59 | 0.73 | 5.22     | 0.69      | 5.41      | 0.20       | 0.01           |
| FR-11                                                     | B     | 536  | 0.55  | 0.55 | 0.66 | 5.82     | 0.56      | 6.37      | 0.30       | 0.63           |
| SR-14                                                     | B     | 1869 | -0.46 | 0.54 | 0.62 | 7.33     | 0.42      | 6.87      | 0.61       | 0.52           |

\* S = Surface  
B = Bottom

Table Q-11 Summary Percentiles for Dissolved Oxygen (mg/l) for September 21 through October 6, 1997

| September 21 - October 6, 1997<br>[Julian Days 264 -279] |        |               |            |               |               |            |               |               |               |
|----------------------------------------------------------|--------|---------------|------------|---------------|---------------|------------|---------------|---------------|---------------|
| Stations                                                 | Depth* | Measured      |            |               | Simulated     |            |               | Difference    |               |
|                                                          |        | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 90%<br>(mg/L) |
| FR-02                                                    | S      | 4.4           | 4.9        | 5.6           | 4.4           | 4.7        | 5.1           | 0.0           | -0.4          |
| FR-02                                                    | B      | 4.4           | 4.8        | 5.3           | 4.7           | 4.9        | 5.1           | 0.3           | -0.2          |
| FR-04                                                    | S      | 3.2           | 3.7        | 4.4           | 4.1           | 4.4        | 4.9           | 0.9           | 0.5           |
| FR-04                                                    | B      | 3.7           | 4.2        | 4.5           | 3.9           | 4.2        | 4.4           | 0.3           | -0.1          |
| FR-06                                                    | S      | 4.0           | 4.6        | 5.5           | 4.7           | 5.1        | 6.1           | 0.7           | 0.7           |
| FR-06                                                    | B      | 3.4           | 3.9        | 4.3           | 3.4           | 3.7        | 3.8           | 0.0           | -0.5          |
| FR-08                                                    | S      | 4.3           | 5.9        | 7.2           | 5.1           | 5.8        | 7.1           | 0.8           | -0.1          |
| FR-08                                                    | B      | 3.6           | 4.9        | 6.8           | 3.8           | 4.7        | 6.5           | 0.3           | -0.3          |
| FR-09                                                    | B      | 4.2           | 6.1        | 7.7           | 4.3           | 5.4        | 6.8           | 0.1           | -0.8          |
| MR-10                                                    | B      | 4.9           | 5.5        | 6.4           | 4.9           | 5.3        | 6.3           | 0.0           | 0.0           |
| FR-11                                                    | B      | 6.5           | 6.8        | 7.2           | 5.9           | 6.8        | 7.6           | -0.6          | 0.4           |
| SR-14                                                    | B      | 7.4           | 8.0        | 8.4           | 6.3           | 7.0        | 7.9           | -1.1          | -0.5          |

\* S = Surface  
B = Bottom

Table Q-12 Summary Statistics for Dissolved Oxygen (mg/l) for September 21 through October 6, 1997

| September 21 - October 6, 1997<br>[Julian Days 264 -279] |       |      |       |      |      |             |              |              |               |      |
|----------------------------------------------------------|-------|------|-------|------|------|-------------|--------------|--------------|---------------|------|
| Station                                                  | Depth | N    | ME    | AME  | RMS  | Mean<br>Obs | StDev<br>Obs | Mean<br>Pred | StDev<br>Pred | R^2  |
| FR-02                                                    | S     | 1152 | -0.21 | 0.33 | 0.42 | 4.97        | 0.49         | 4.76         | 0.27          | 0.44 |
| FR-02                                                    | B     | 1497 | 0.03  | 0.26 | 0.34 | 4.83        | 0.46         | 4.86         | 0.17          | 0.63 |
| FR-04                                                    | S     | 482  | 0.73  | 0.76 | 0.86 | 3.76        | 0.47         | 4.48         | 0.30          | 0.12 |
| FR-04                                                    | B     | 1495 | 0.04  | 0.24 | 0.31 | 4.15        | 0.34         | 4.19         | 0.17          | 0.20 |
| FR-06                                                    | S     | 1558 | 0.62  | 0.62 | 0.69 | 4.64        | 0.56         | 5.25         | 0.56          | 0.72 |
| FR-06                                                    | B     | 1550 | -0.25 | 0.34 | 0.45 | 3.89        | 0.35         | 3.64         | 0.15          | 0.00 |
| FR-08                                                    | S     | 1192 | 0.14  | 0.57 | 0.67 | 5.82        | 1.03         | 5.96         | 0.70          | 0.61 |
| FR-08                                                    | B     | 2141 | -0.16 | 1.23 | 1.48 | 5.06        | 1.24         | 4.90         | 0.93          | 0.01 |
| FR-09                                                    | B     | 1701 | -0.50 | 0.84 | 0.77 | 5.94        | 1.19         | 5.44         | 0.89          | 0.78 |
| MR-10                                                    | B     | 1518 | -0.14 | 0.46 | 0.53 | 5.56        | 0.53         | 5.42         | 0.56          | 0.30 |
| FR-11                                                    | B     | 1171 | -0.03 | 0.30 | 0.36 | 6.84        | 0.34         | 6.81         | 0.62          | 0.77 |
| SR-14                                                    | B     | 1691 | -0.92 | 0.92 | 0.98 | 7.99        | 0.37         | 7.07         | 0.61          | 0.76 |

\* S = Surface  
B = Bottom



## **APPENDIX R    1999 DISSOLVED OXYGEN DEFICIT (MOVING AVERAGE) COMPARISONS**





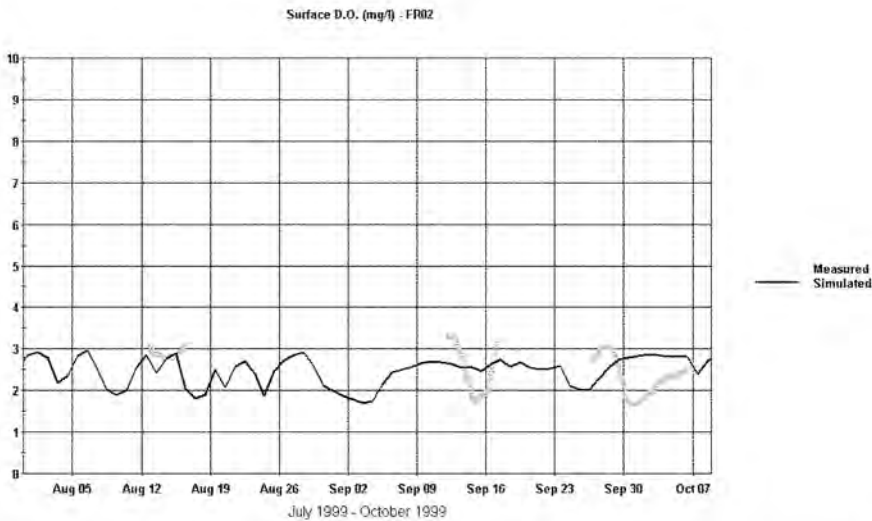


Figure R-1 Dissolved Oxygen Deficit Moving Average at FR-02 (Surface) for July 31 through October 13, 1999

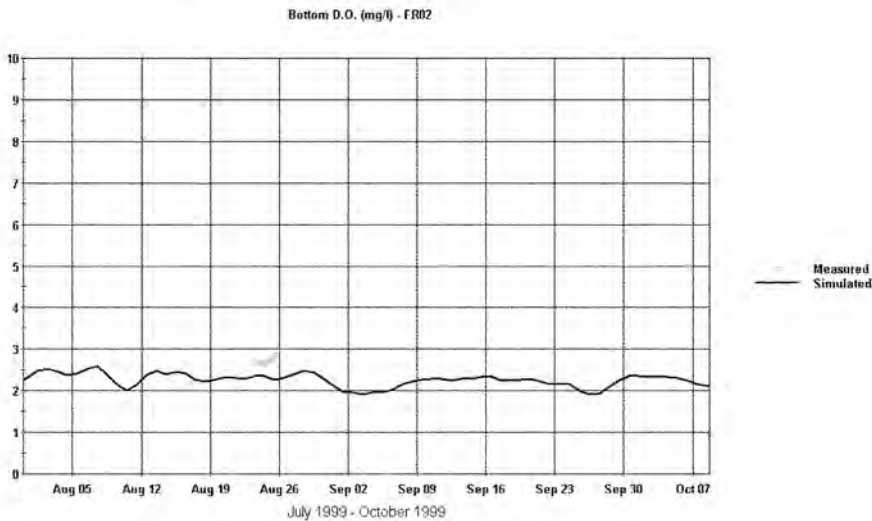


Figure R-2 Dissolved Oxygen Deficit Moving Average at FR-02 (Bottom) for July 31 through October 13, 1999

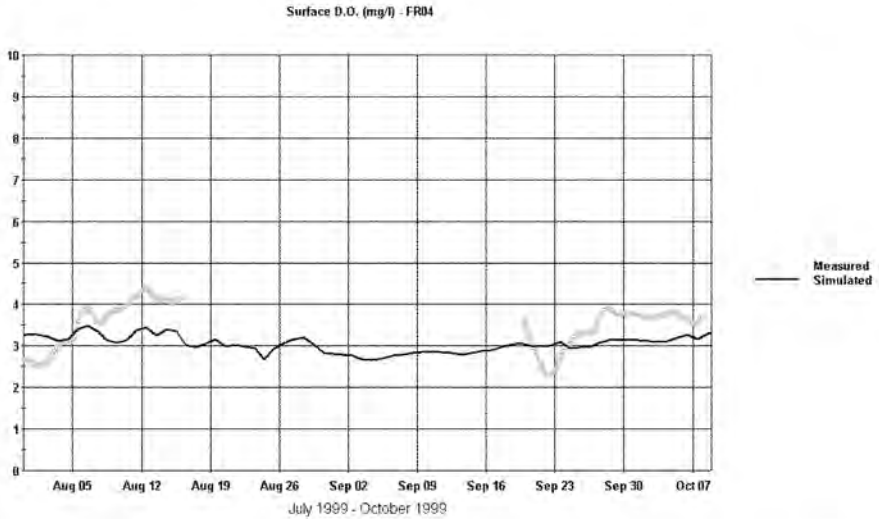


Figure R-3 Dissolved Oxygen Deficit Moving Average at FR-04 (Surface) for July 31 through October 13, 1999

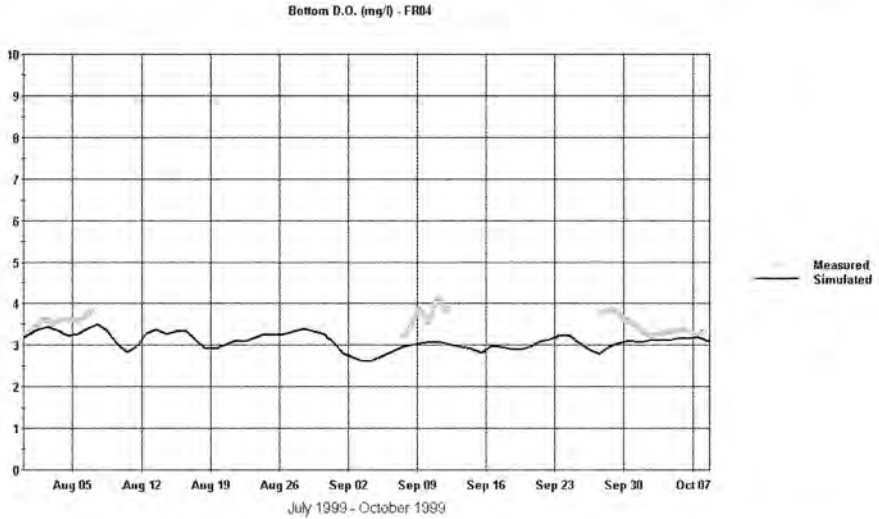


Figure R-4 Dissolved Oxygen Deficit Moving Average at FR-04 (Bottom) for July 31 through October 13, 1999

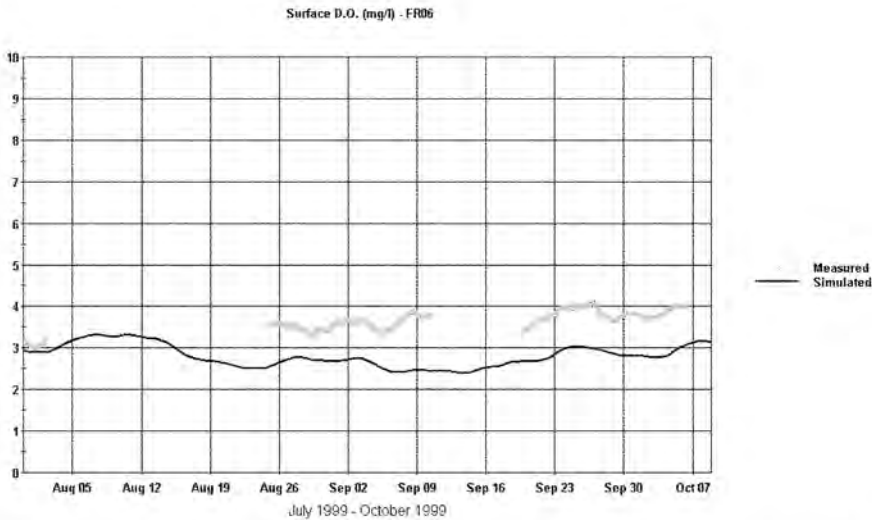


Figure R-5 Dissolved Oxygen Deficit Moving Average at FR-06 (Surface) for July 31 through October 13, 1999

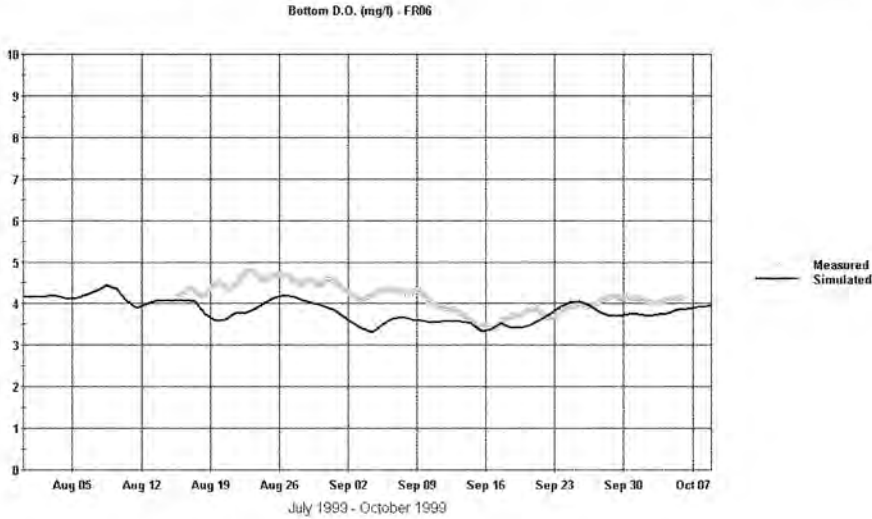


Figure R-6 Dissolved Oxygen Deficit Moving Average at FR-06 (Bottom) for July 31 through October 13, 1999

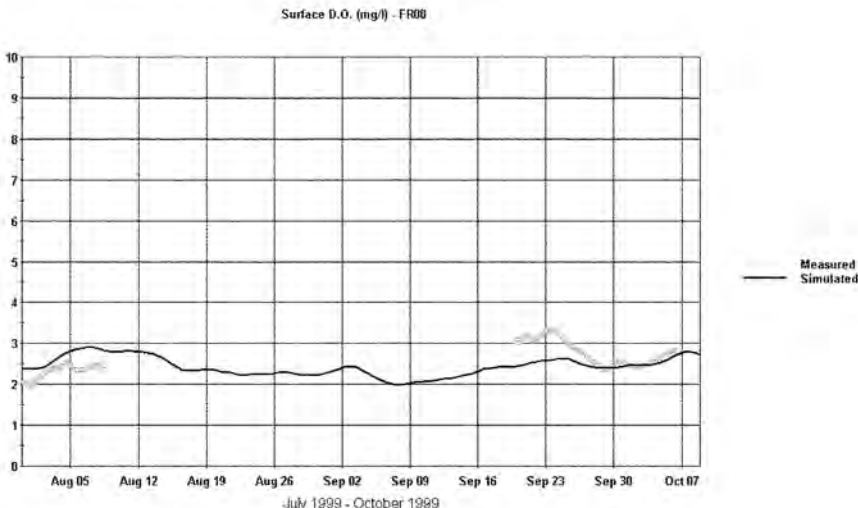


Figure R-7 Dissolved Oxygen Deficit Moving Average at FR-08 (Surface) for July 31 through October 13, 1999

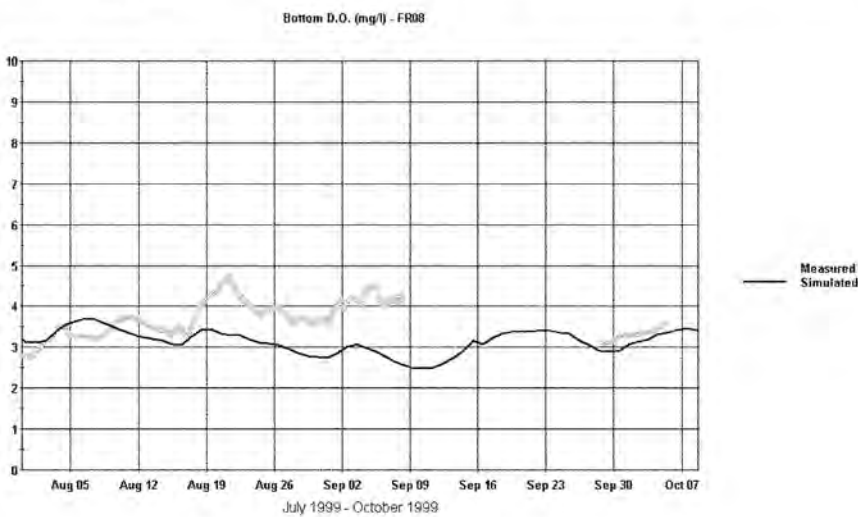


Figure R-8 Dissolved Oxygen Deficit Moving Average at FR-08 (Bottom) for July 31 through October 13, 1999

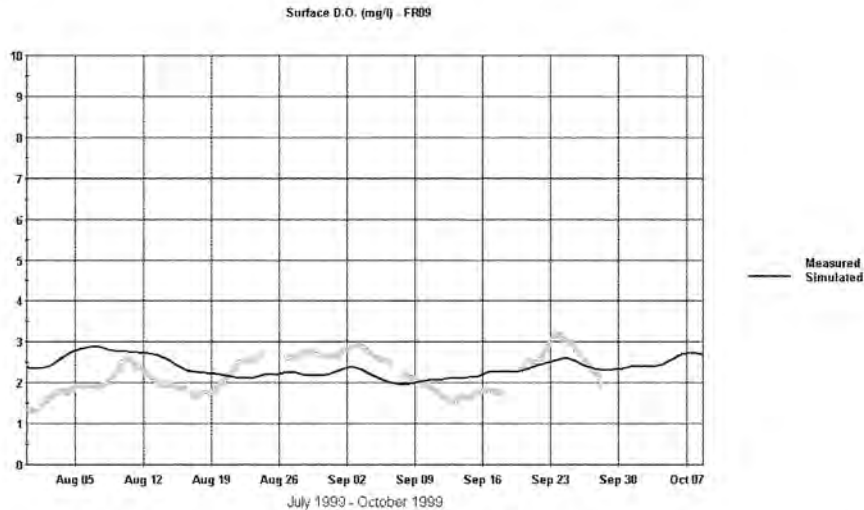


Figure R-11 Dissolved Oxygen Deficit Moving Average at FR-09 (Surface) for July 31 through October 13, 1999

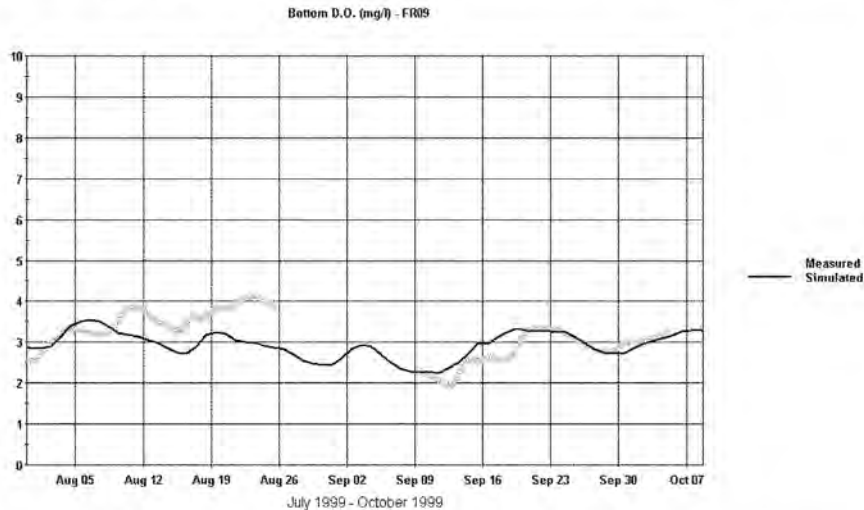


Figure R-9 Dissolved Oxygen Deficit Moving Average at FR-09 (Bottom) for July 31 through October 13, 1999

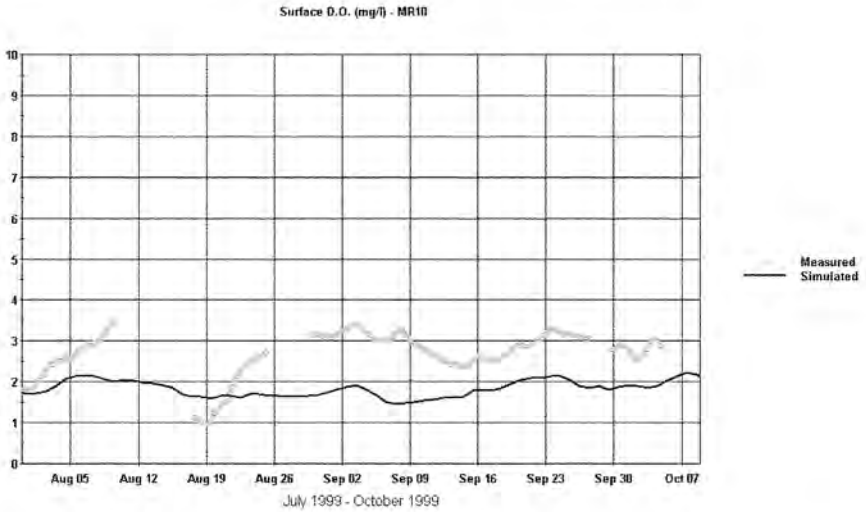


Figure R-10 Dissolved Oxygen Deficit Moving Average at MR-10 (Surface) for July 31 through October 13, 1999

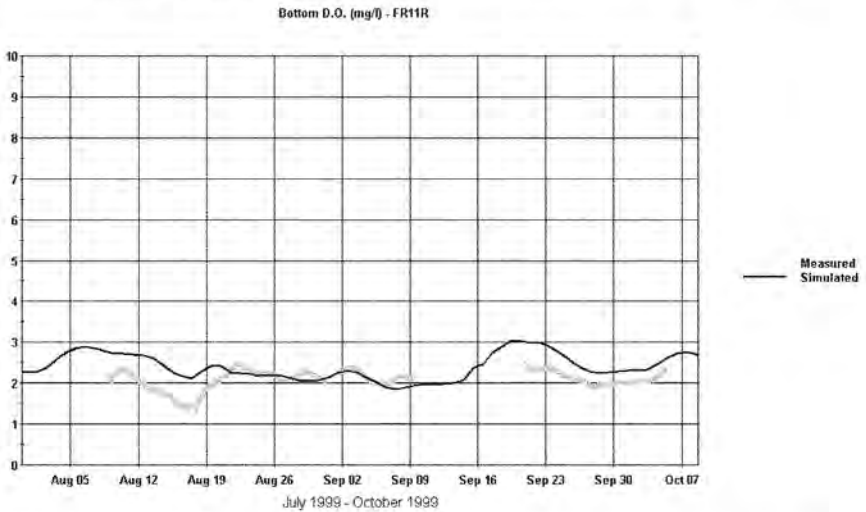


Figure R-11 Dissolved Oxygen Deficit Moving Average at FR-11R (Bottom) for July 31 through October 13, 1999

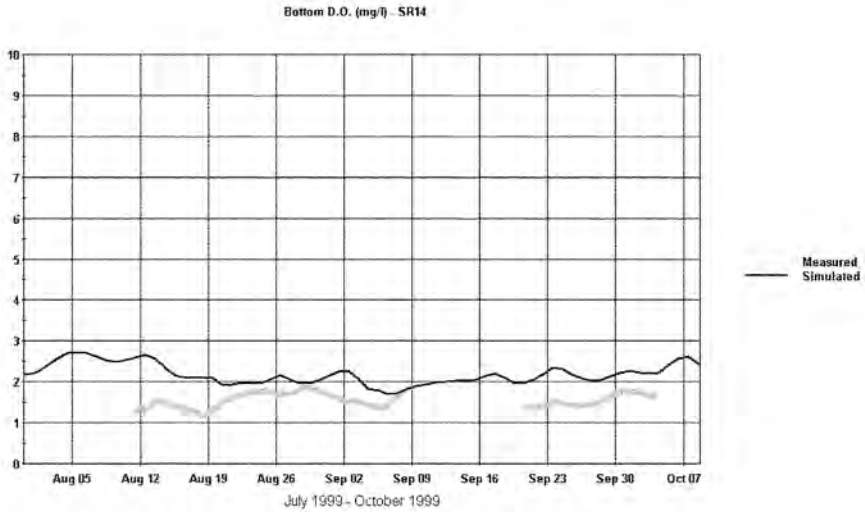


Figure R-12 Dissolved Oxygen Deficit Moving Average at SR-14 (Bottom) for July 31 through October 13, 1999

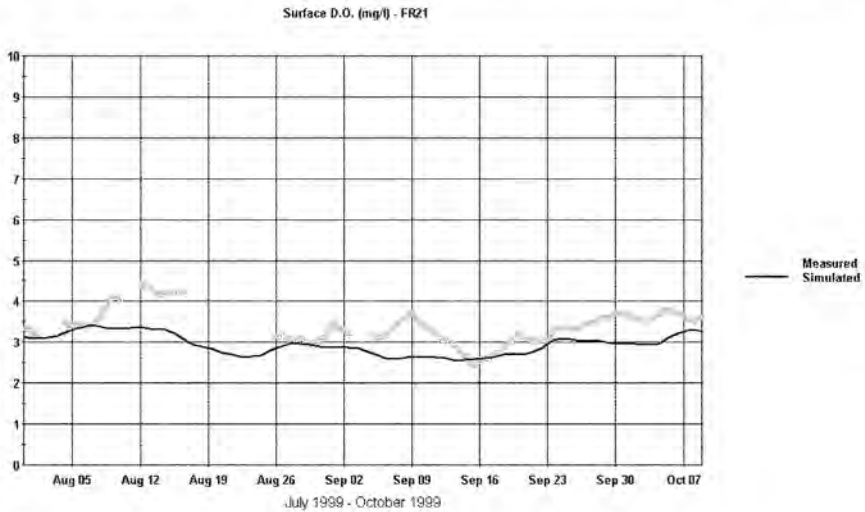


Figure R-13 Dissolved Oxygen Deficit Moving Average at FR-21 (Surface) for July 31 through October 13, 1999

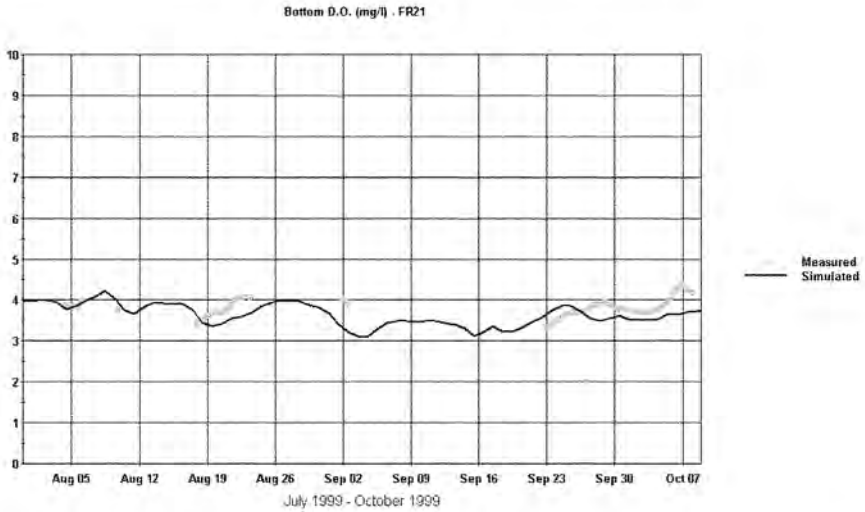


Figure R-14 Dissolved Oxygen Deficit Moving Average at FR-21 (Bottom) for July 31 through October 13, 1999

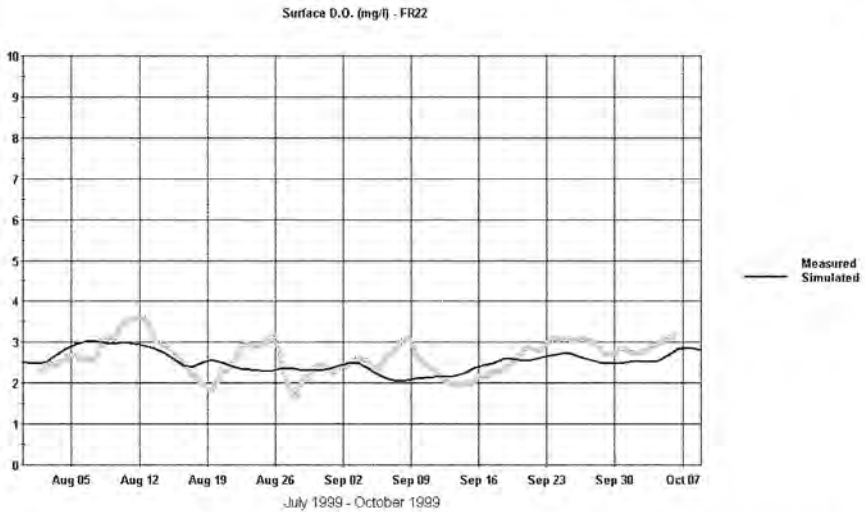


Figure R-15 Dissolved Oxygen Deficit Moving Average at FR-22 (Surface) for July 31 through October 13, 1999



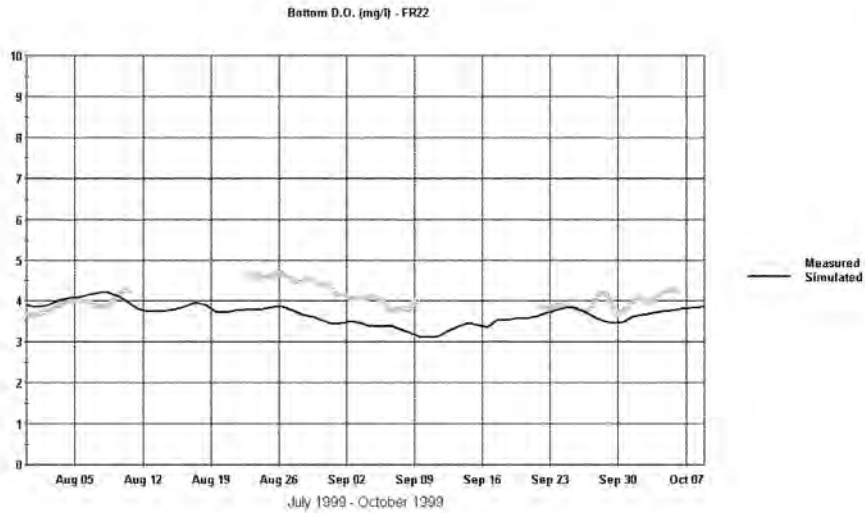


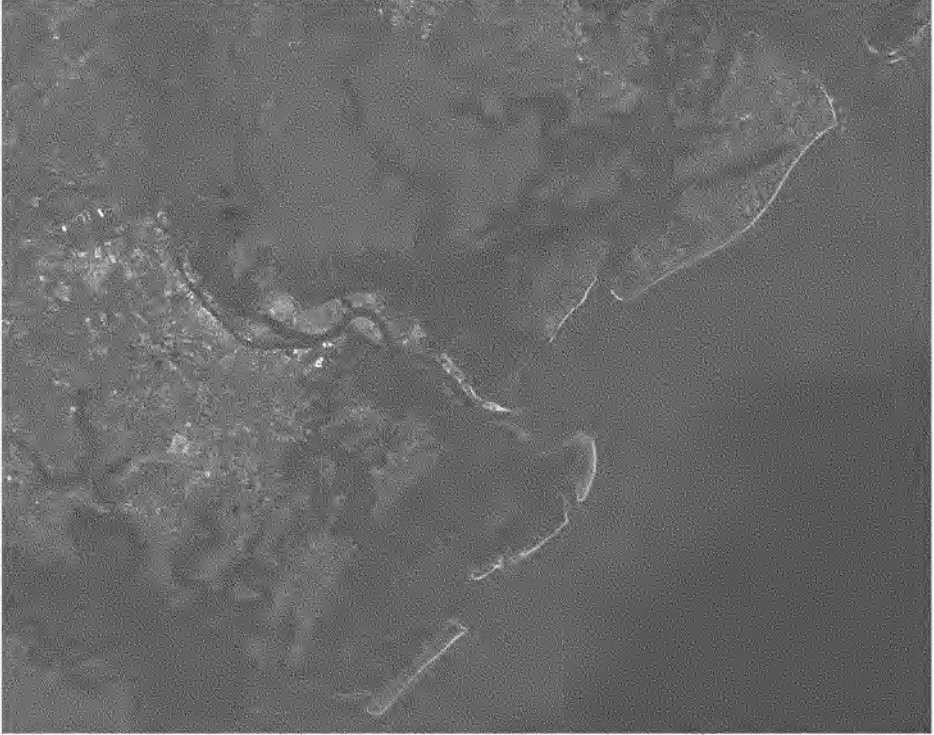
Figure R-16 Dissolved Oxygen Deficit Moving Average at FR-22 (Bottom) for July 31 through October 13, 1999



## **APPENDIX S     UNCERTAINTY ANALYSIS OF THE SHEP ENHANCED GRID MODEL**



## Uncertainty Analysis of the SHEP Enhanced Grid Model



Prepared by:  
Kinetic Analysis Corporation  
Savannah, GA, USA

May 18, 2005



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# Chapter 1

## Executive Summary

The Enhanced Grid version of the EFDC model of the lower Savannah River was examined and compared to long term station data at four locations. Unlike the TMDL version of the model, a complete seven year run was not possible with the same configuration used for the calibration/verification runs using data from 1997 and 1999. The results in this report are based on two runs, one of three years, the other of four, on either side of a critical condition causing abnormal model termination. This termination appears to be the result of instabilities caused by combinations of time step, model grid, and unusual flow conditions.

Even with the stability problems, the Enhanced Grid model appears to represent a significant improvement over the TMDL model. It has the potential to become an extremely useful tool in studying the lower Savannah River. However, the inability to conduct seven year test runs is a source of serious concern with respect to the suitability of the model for predictive purposes. Therefore, Kinetic Analysis Corporation does not recommend the operational use of the Enhanced Grid model for predictive modeling of bathymetric changes until the stability issues can be resolved.



## **Part I**

# **Introduction and Analysis**



## Chapter 2

# Introduction and Methodology

### 2.1 Introduction

This document contains the final report of Kinetic Analysis Corporation (KAC) on an analysis of the uncertainty in predictions from the Enhanced Grid (ENHG) configuration of the EFDC Model of the lower Savannah River. An Uncertainty Analysis essentially consists of running a model under known conditions, then varying the input variables in such a way as to observe the reaction of the model so as to be able to anticipate the predictive ability of the model. In this study, emphasis is made on salinity calculations at the four USGS long term monitoring stations. Salinity is a good indicator of overall performance of the model as the transport of salt is dependent on both the horizontal and vertical mixing and mass transport in the model. Additional analysis is provided on the potential for the uncertainty in salinity to propagate through to dissolved oxygen calculations.

KAC initially attempted to conduct this study in the same manner as that used to evaluate the TMDL model (see the Draft Report, Uncertainty Analysis of the TMDL model). In summary, KAC obtained the source code and input file configuration from TetraTech. KAC then compiled the code and executed seven year runs (Jan 97 - Dec 03) for the official configuration of the model as well as other configurations with modified time steps, bottom depths, friction, etc. In all cases the model was stable and produced usable results. This approach proved unsuccessful with the ENHG configuration. Numerous delays crept in to the process because both TetraTech (Tt) and KAC were unable to successfully run a complete seven year baseline using the same configuration and input files used for the calibration and verification runs. After considerable analysis and discussion, three issues were identified:

- 1) Different configuration files (due to numerous experiments by multiple individuals in both organizations attempting to address the problem);
- 2) Different compilers and settings;
- 3) Model stability at different step sizes and configurations.

Once the configuration file issue was resolved, it appeared at first that the difference in compilers was causing problems, and considerable time and effort was spent exploring

the impact of various operating systems, compilers, and compiler options on the code. The final result of those analyses were that the EFDC code is relatively portable and stable, and provided care is taken to ensure identical floating point treatment, platform and compiler choice is not a factor. Results are nearly identical even across a wide range of platforms and compiler selections.

The underlying reason for the differing results now appears to be that the ENHG model has marginal stability at some combinations of step time, flow and tides. These conditions were not encountered during the calibration or verification periods in 97 and 99. The normally negligible differences between compilers and options grew exponentially during conditions of marginal stability, resulting in crashes at different times depending on the exact platform, compiler, and even configuration of a given compiler. The following figure (2.1) shows the relative flow frequencies at Clio for the overall study period (97-03), a longer term (1986-03), and the two subsets.

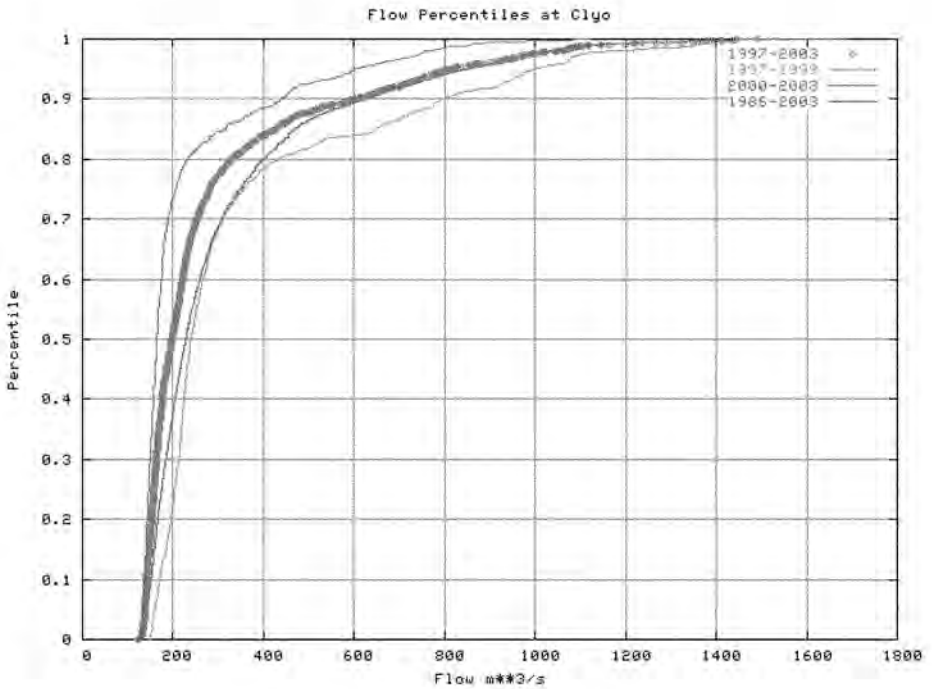


Figure 2.1: Flow percentiles at Clio

As is readily seen, the two subsets form two distinct populations from either the over-

## 2.1. INTRODUCTION

7

all study period or of the longer term data, especially when the low to medium flows are examined (figure 2.2) The 2000-2003 time frame is anomalous in many respects. For example, in the 1986 to 2003 time frame, only 10 percent of daily flows were less than 150  $\text{m}^3/\text{s}$ . In the 2000-2003 time frame, over 30 percent of the flows were under this value, while in the 1997-1999 time frame, less than 2 percent of flows were below 150  $\text{m}^3/\text{s}$ . Given that the model was calibrated to the 1997-1999 time frame, the high frequencies of low flows in the 2000-2003 time frame make it a good test of the model under "unknown" conditions, and a successful run is highly desirable.

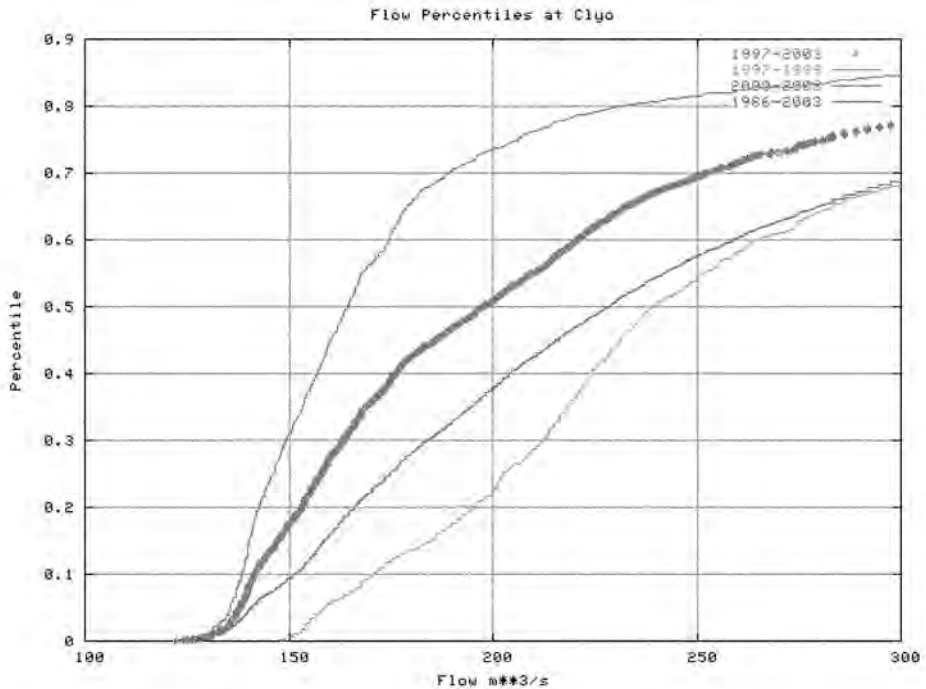


Figure 2.2: Flow percentiles at Clio, 100-300  $\text{m}^3/\text{s}$

In conclusion, issues one and two (configuration and compiler/platform) have been resolved to the satisfaction of both Tt and KAC, with issue three, the stability of the model under different combinations of flow, time step, and boundary, remaining unresolved. KAC has made several recommendations to Tt to further explore this matter. As of the date of this report and the conclusion of the calibration/verification phase, the full cause and impact of these instability issues remain unresolved. In order to complete this report,

two independent runs were made to avoid the point at which the model aborted. KAC has several recommendations based on this experience, which are included in chapter 5.

This document contains three major sections:

- 1) This introduction;
- 2) A comparison of the available results of the ENHG model with the TMDL model;
- 3) The potential impact of error in salinity on dissolved oxygen calculations in WASP;
- 4) Recommendations and observations;
- 5) Supporting graphics.

## 2.2 Methodology

As much as possible, this study was conducted in the same manner as the assessment of the TMDL model. As noted above, the model was compiled locally on using the Intel, Lahey, and GNU Fortran compilers on both Linux (2.6.4-52-smp and 2.6.9-1.667smp kernels) and Microsoft Windows XP sp1 platforms. The graphs and data to support this analysis were created using the Linux/Intel combination for performance reasons. TetraTech provided the results of their runs (1997-1999 and 2000-2003), which were compared to the local runs and found to be virtually identical.

Unlike the TMDL model, which was run with multiple, alternate scenarios to more fully assess the potential uncertainty in forecasts, the ENHG grid was only run operationally using the provided configuration. Tests were run with alternate configurations, however, some were stable while others were not. Therefore, these alternate scenarios were not analyzed.

For each available data point at a station, the observed value was compared with closest modeled value to that point. This resulted in from 22,000 (Houlihan) to over 70,000 (FWS) points of comparison. The difference between observed and computed was tabulated by salinity, flow at Clyo, and tides, enabling the stratification of error by any of these three variables. Error by salinity is the pure error in the model, while stratification of error by flow and by tides provide indications of how error changes with changes in these two key boundary conditions. These output files were analyzed using the "R" statistics package:

R Development Core Team (2004). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL <http://www.R-project.org>.

The graphics were created using C shell scripts and the GNUplot program, version 3.7. Note that some of the graphs are clipped, or contain bins with zero values, due to the lack of data resulting from the inability to complete the seven year run.

This document was produced using the LaTeX text processing system.



## Chapter 3

### Comparisons with TMDL model

These graphs show the median errors and 50 percent error limits for both the TMDL model, the two runs of the ENHG configuration, the combined results of the split ENHG run. The "A" run is 1997-1999, while the "B" runs is from 2000-2003. As can be seen from these graphs, the performance of of the ENHG model is not consistent between the two periods. This is unlike the TMDL model, which had relatively consistent error bands when partitioned in to two runs.

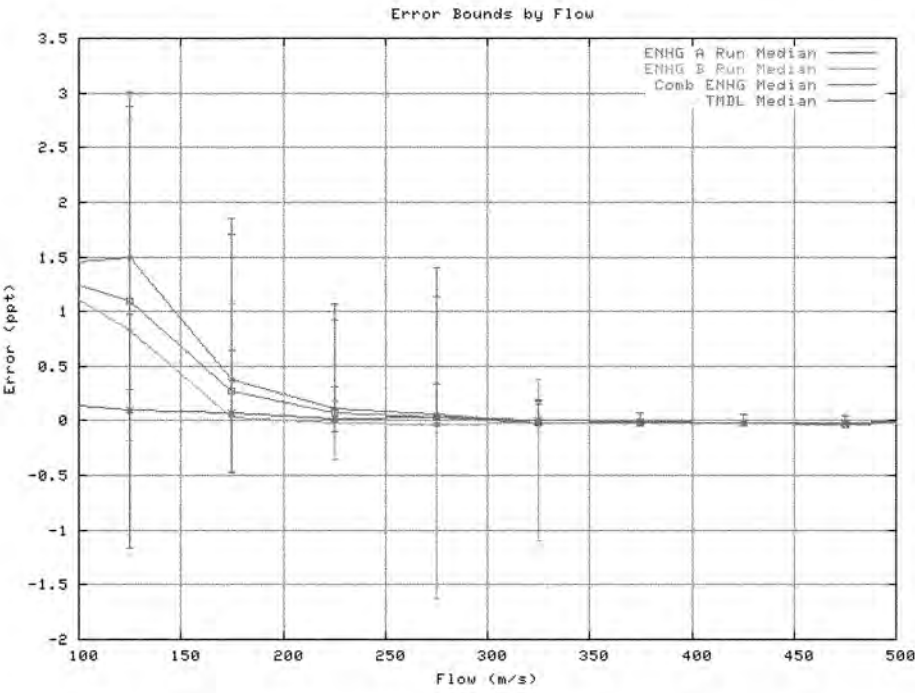


Figure 3.1: Comparison of error bounds, TMDL vs. ENHG at Houlihan Bridge

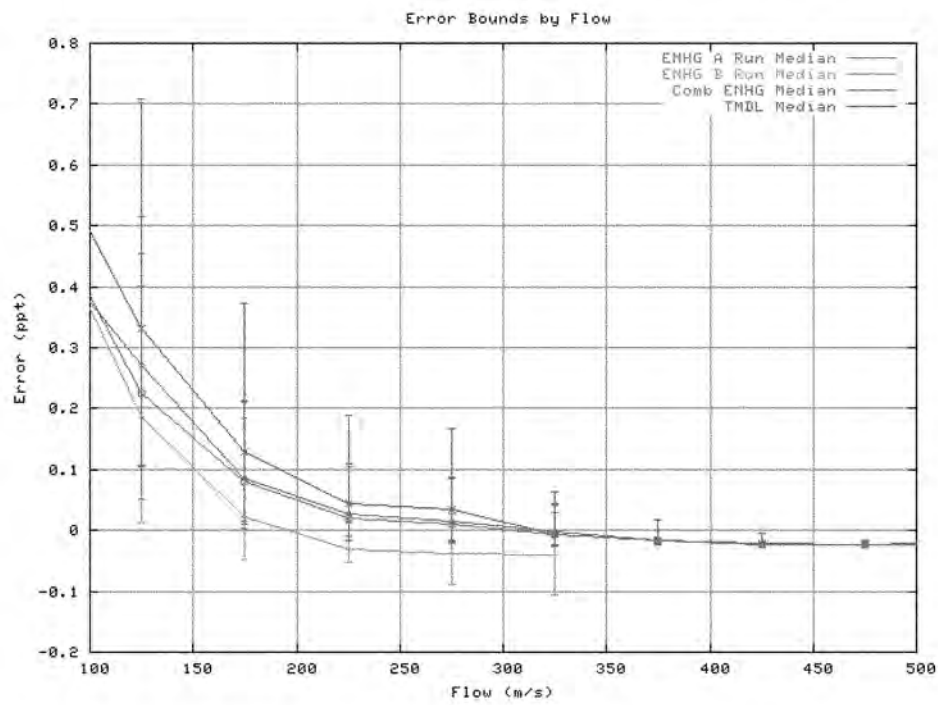


Figure 3.2: Comparison of error bounds, TMDL vs. ENHG at US FWS Dock

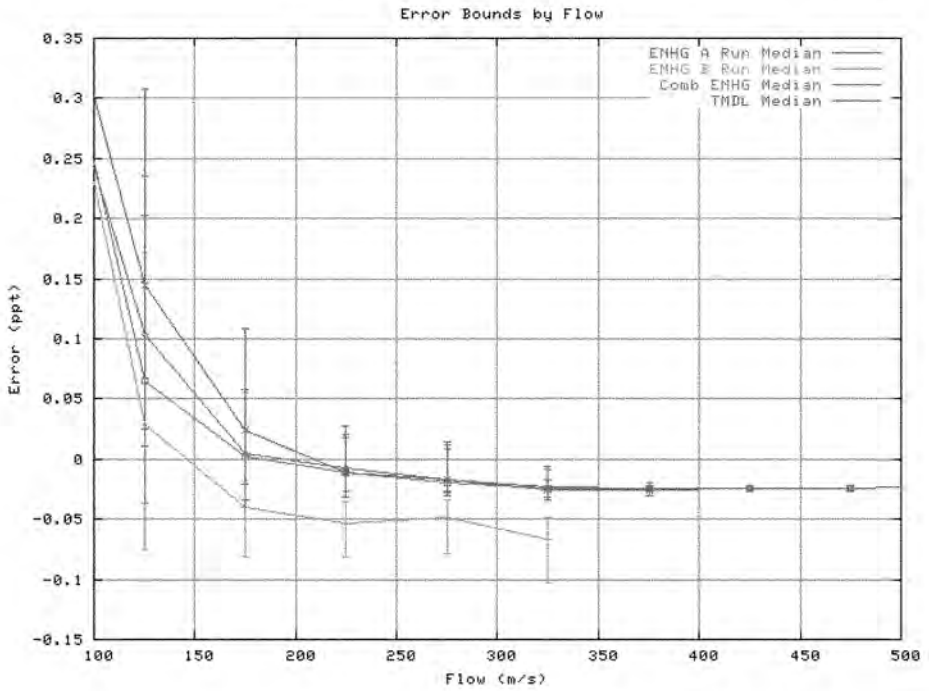


Figure 3.3: Comparison of error bounds, TMDL vs. ENHG at Lucknow Canal

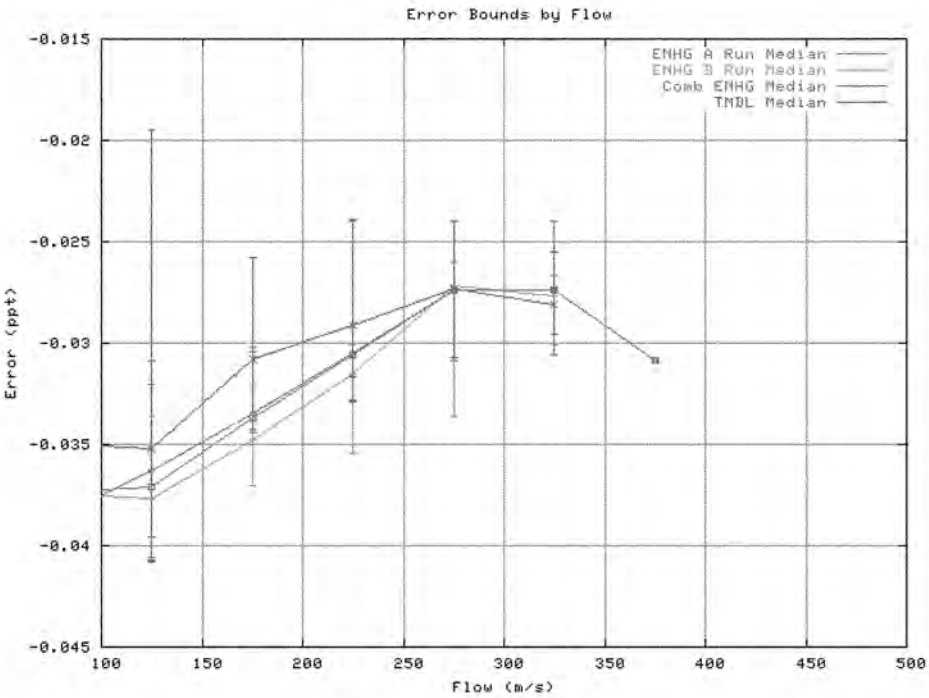


Figure 3.4: Comparison of error bounds, TMDL vs. ENHG at I-95 Bridge



## Chapter 4

# Assessment of induced error in DO calculations

In order to assess the potential impact of salinity errors on DO calculations, the impact of salinity errors on dissolved oxygen (DO) saturation was estimated as follows. For each salinity comparison, the concurrent DO saturation value was computed (Brown, Skougstad, and Fishman, 1970) for both observed and modeled salinity/temperature combinations. The difference between the computed saturation values is here called the "induced error". It provides an indication of the potential propagation of error into the water quality calculations.

Note that these should be considered lower limits to DO errors. In other words, the dissolved oxygen uncertainty can probably be no better than that indicated below, since the DO calculation depends in part on salinity.

### 4.1 Performance on 1997-1999 run

This series of graphs shows induced DO error based on the 1997-1999 run.

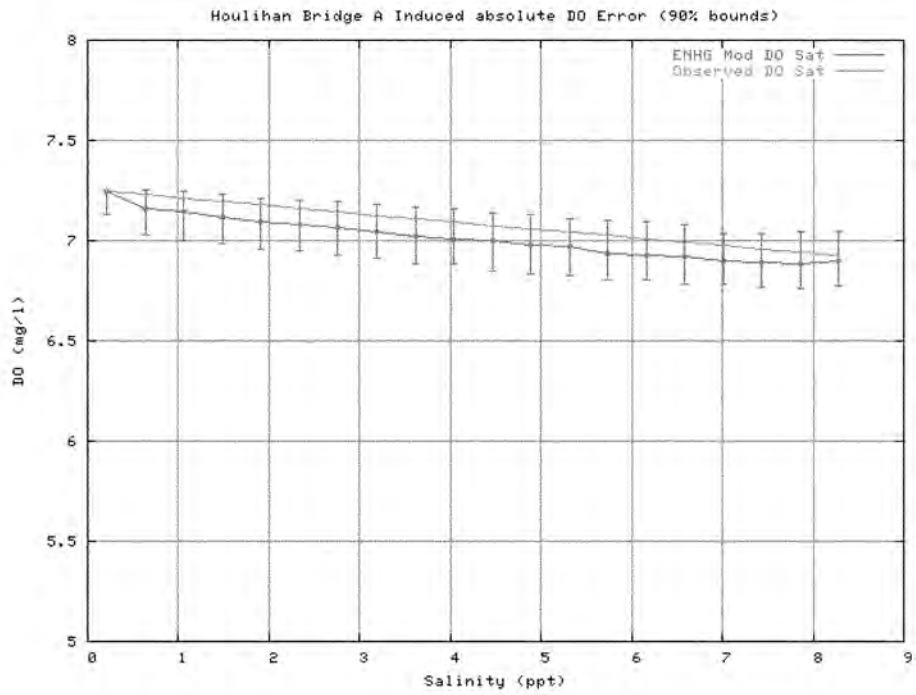


Figure 4.1: DO Absolute Error Analysis, Houlihan Bridge, 97-99



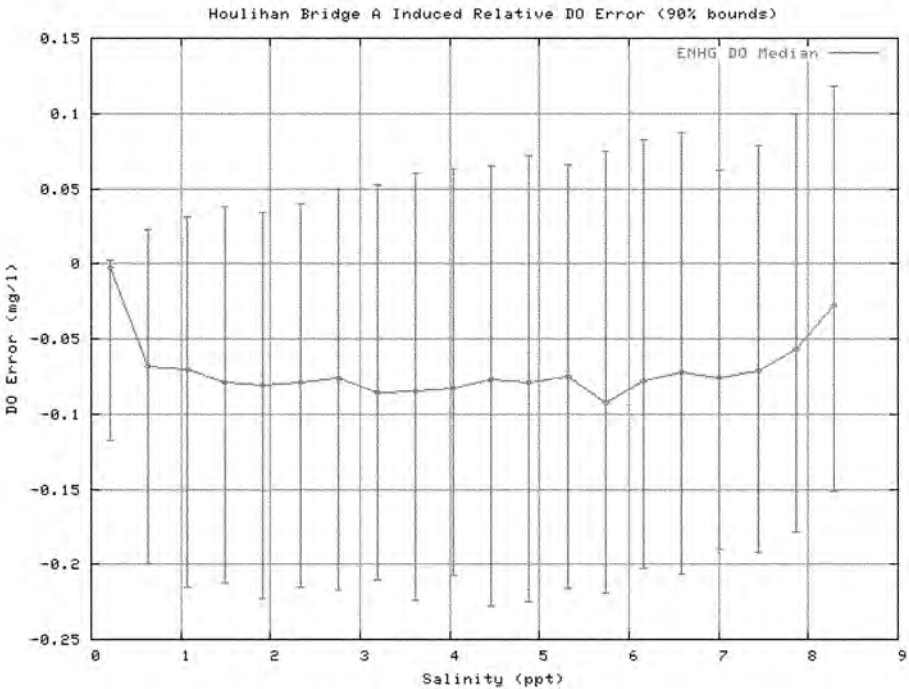


Figure 4.2: DO Relative Error Analysis, Houlihan Bridge, 97-99

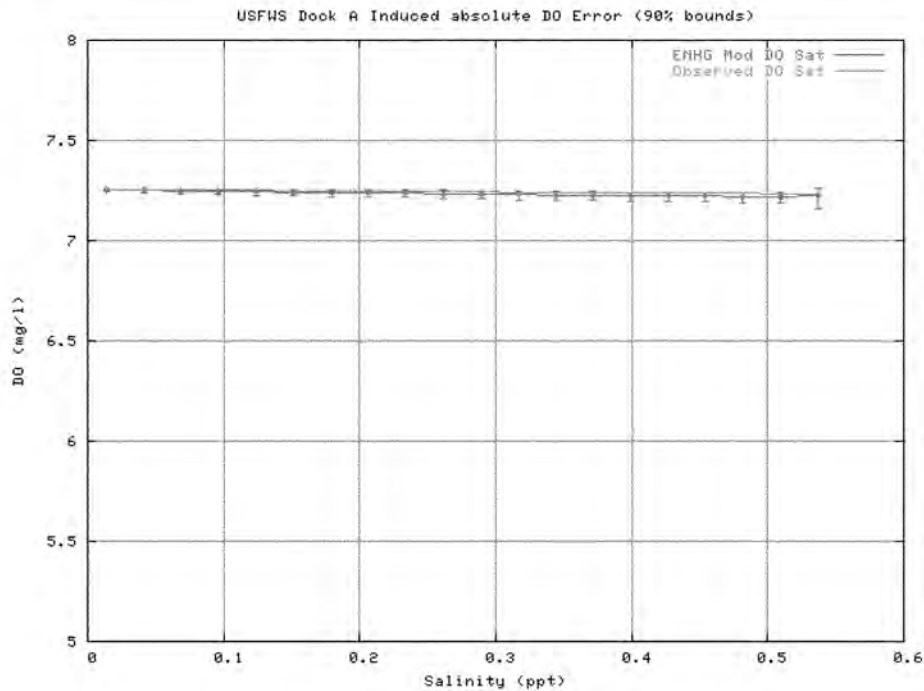


Figure 4.3: DO Absolute Error Analysis, USFWS Dock, 97-99

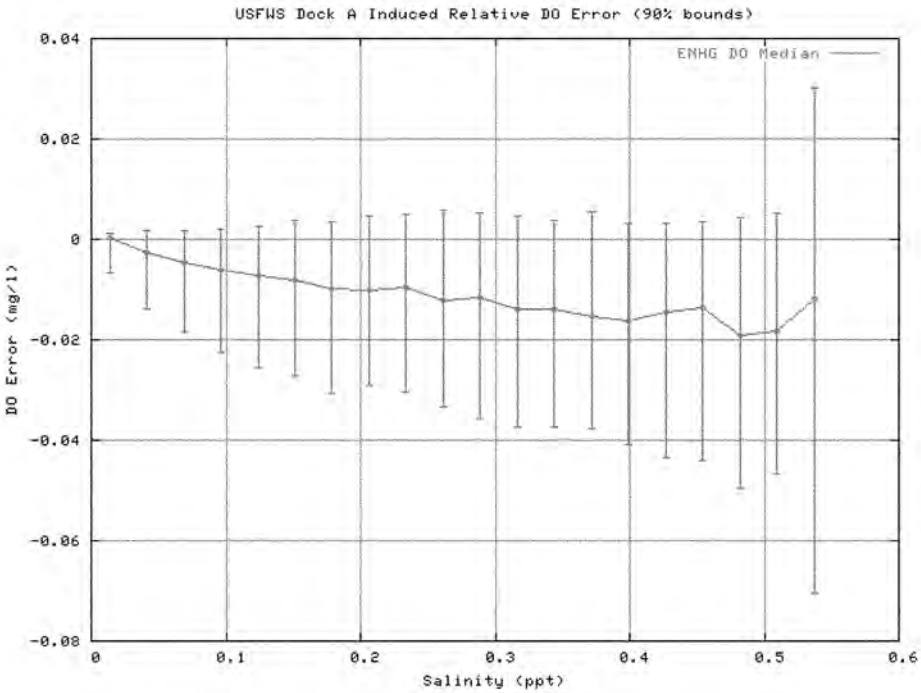


Figure 4.4: DO Relative Error Analysis, USFWS Dock, 97-99

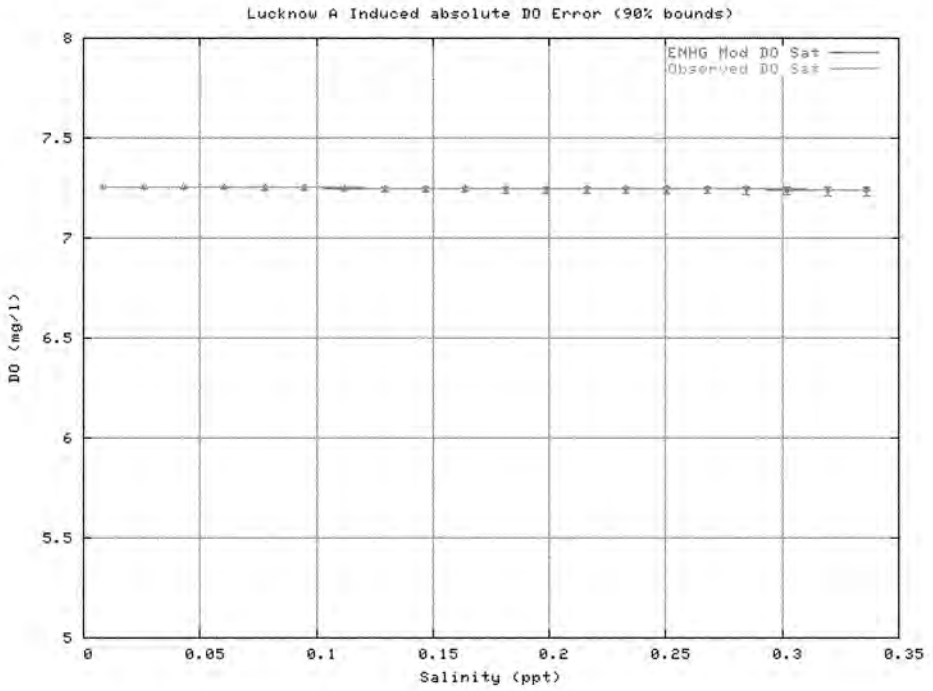


Figure 4.5: DO Absolute Error Analysis, Lucknow Canal, 97-99

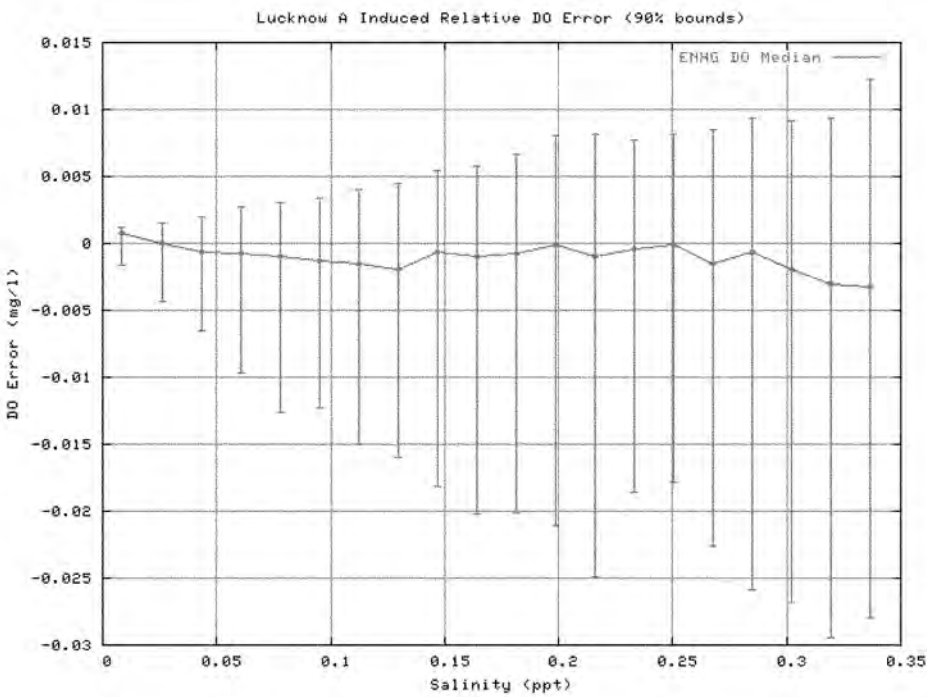


Figure 4.6: DO Relative Error Analysis, Lucknow Canal, 97-99

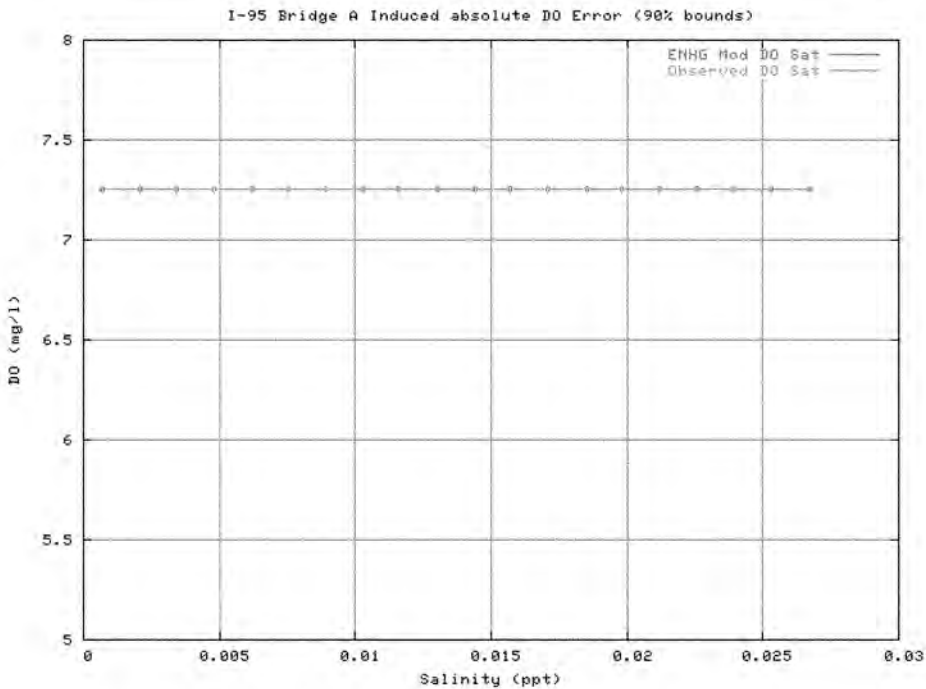


Figure 4.7: DO Absolute Error Analysis, I-95 Bridge, 97-99

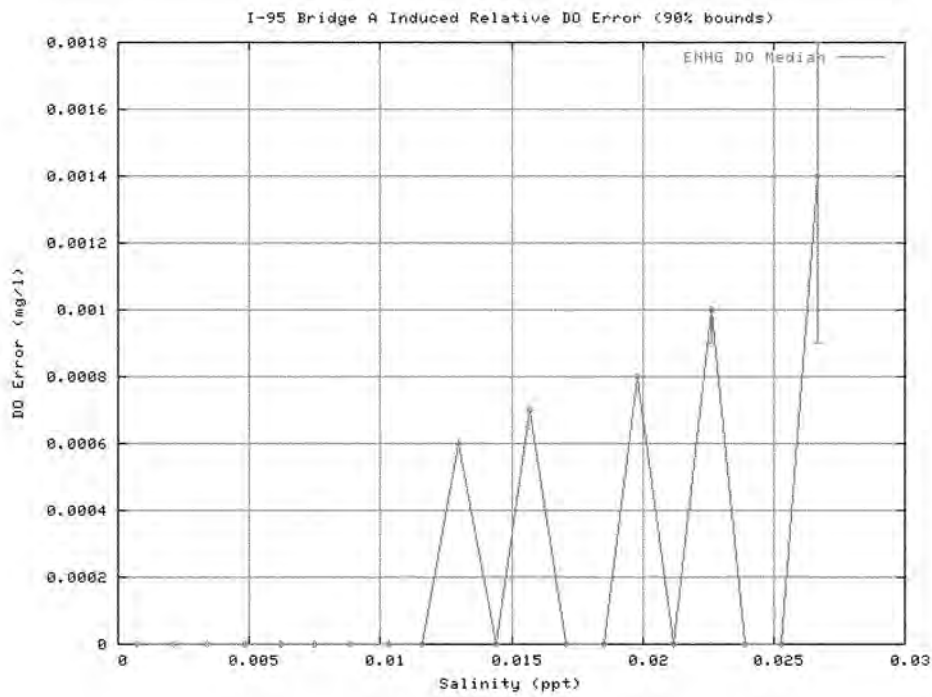


Figure 4.8: DO Relative Error Analysis, I-95 Bridge, 97-99

## 4.2 Performance on 2000-2003 run

This series of graphs shows induced DO error based on the 2000-2003 run.

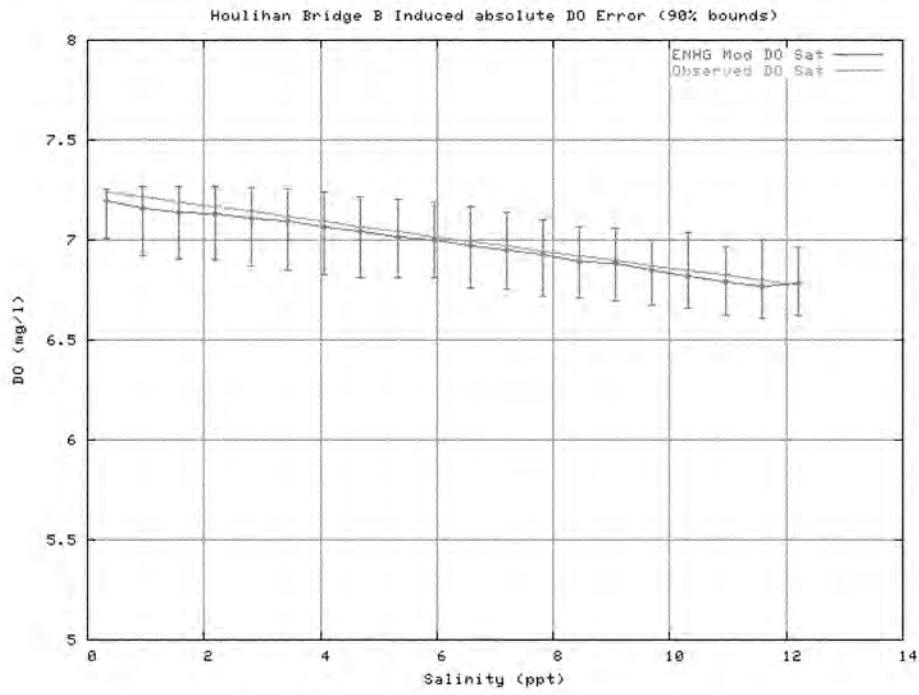


Figure 4.9: DO Absolute Error Analysis, Houlihan Bridge, 00-03



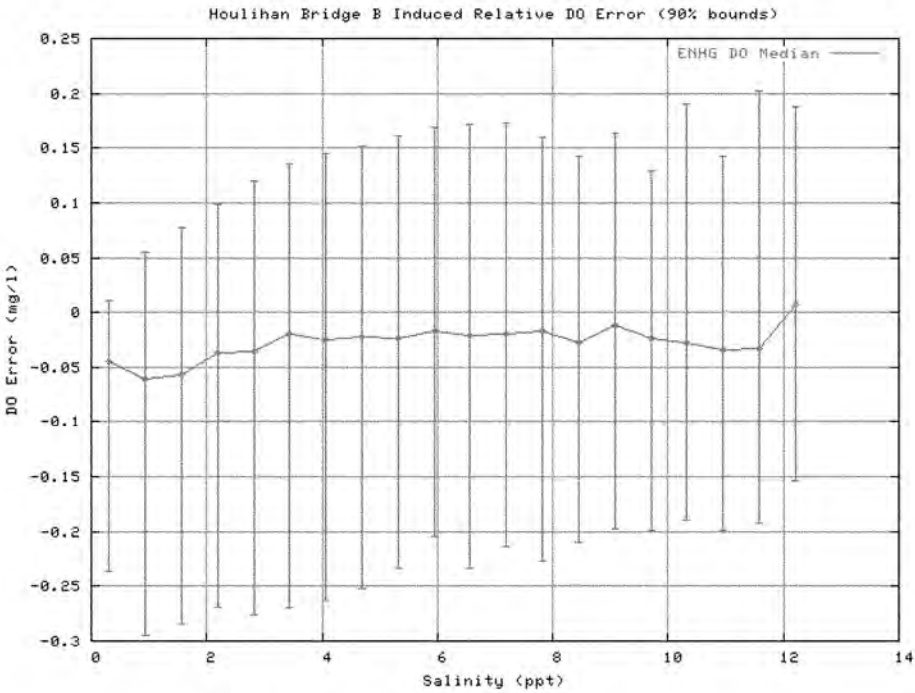


Figure 4.10: DO Relative Error Analysis, Houlihan Bridge, 00-03

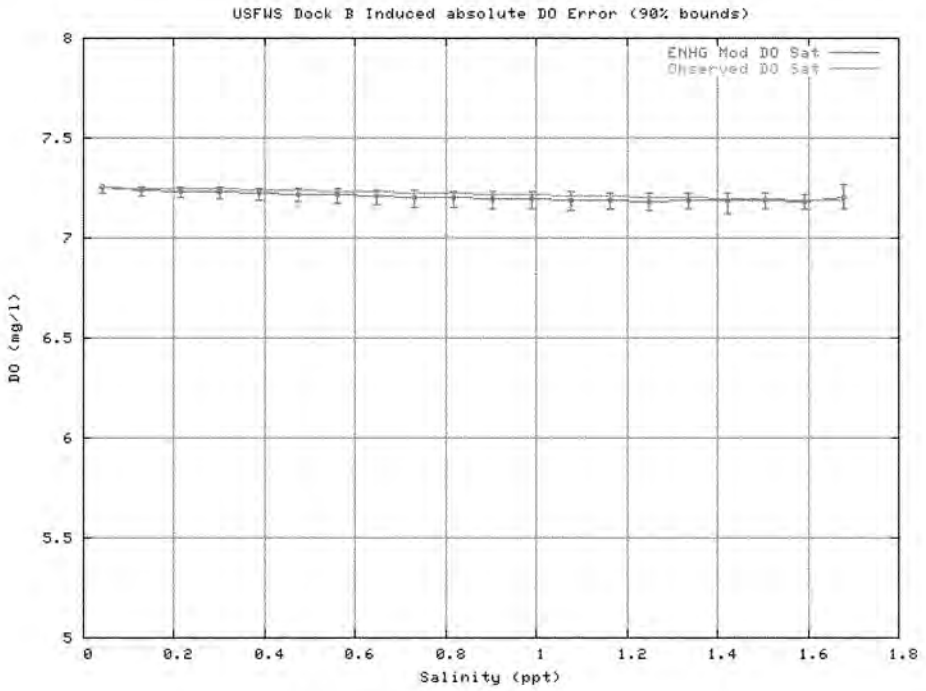


Figure 4.11: DO Absolute Error Analysis, USFWS Dock, 00-03

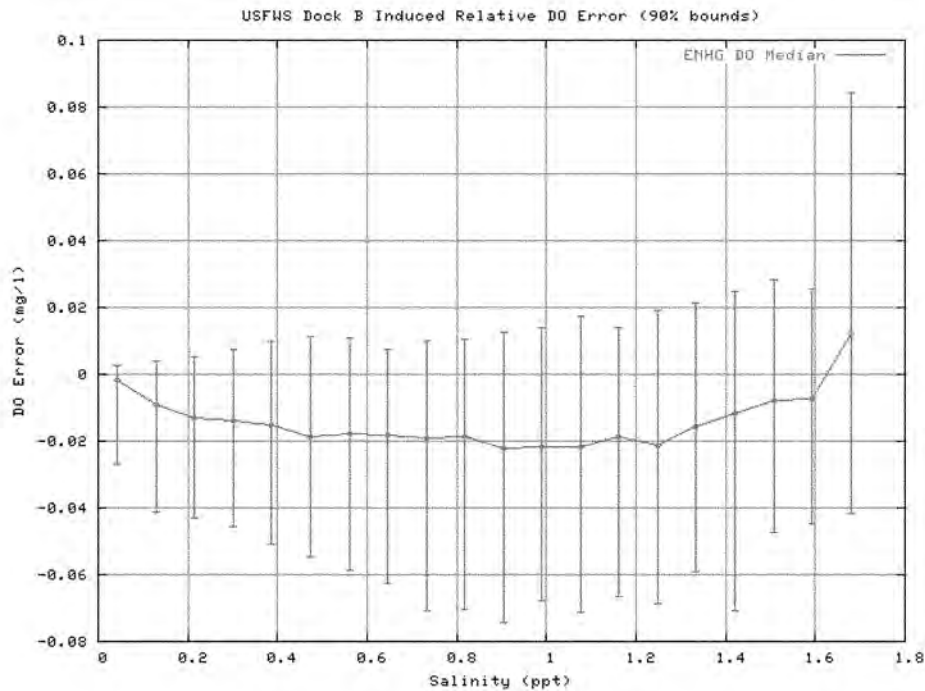


Figure 4.12: DO Relative Error Analysis, USFWS Dock, 00-03

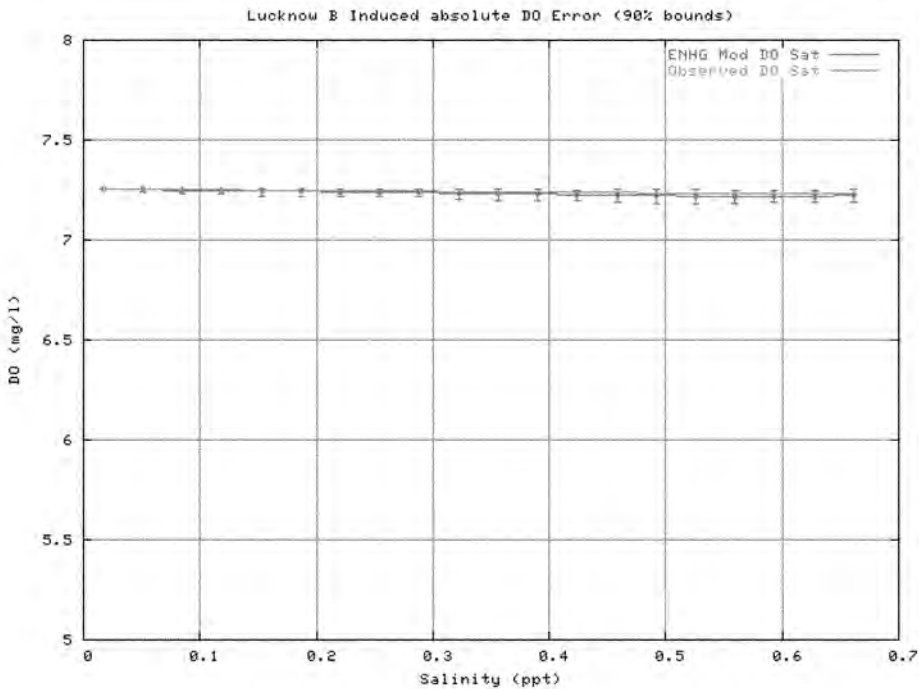


Figure 4.13: DO Absolute Error Analysis, Lucknow Canal, 00-03

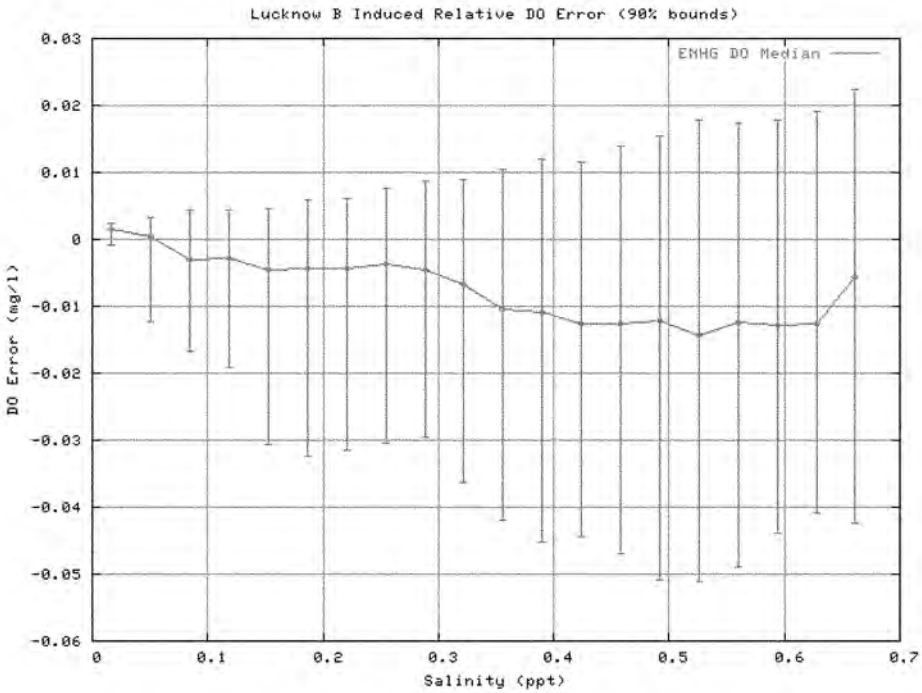


Figure 4.14: DO Relative Error Analysis, Lucknow Canal, 00-03

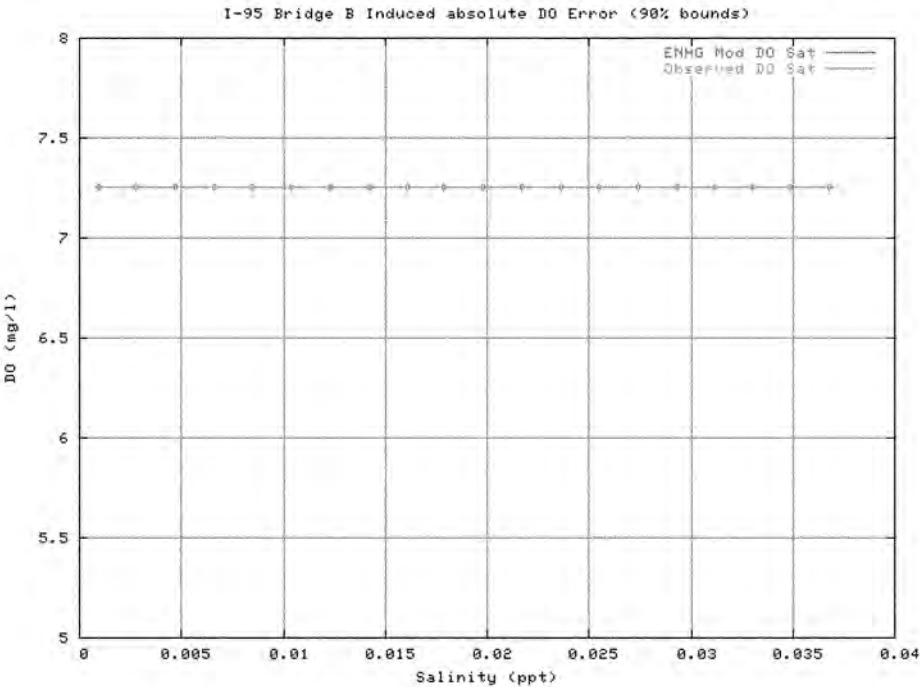


Figure 4.15: DO Absolute Error Analysis, I-95 Bridge, 00-03

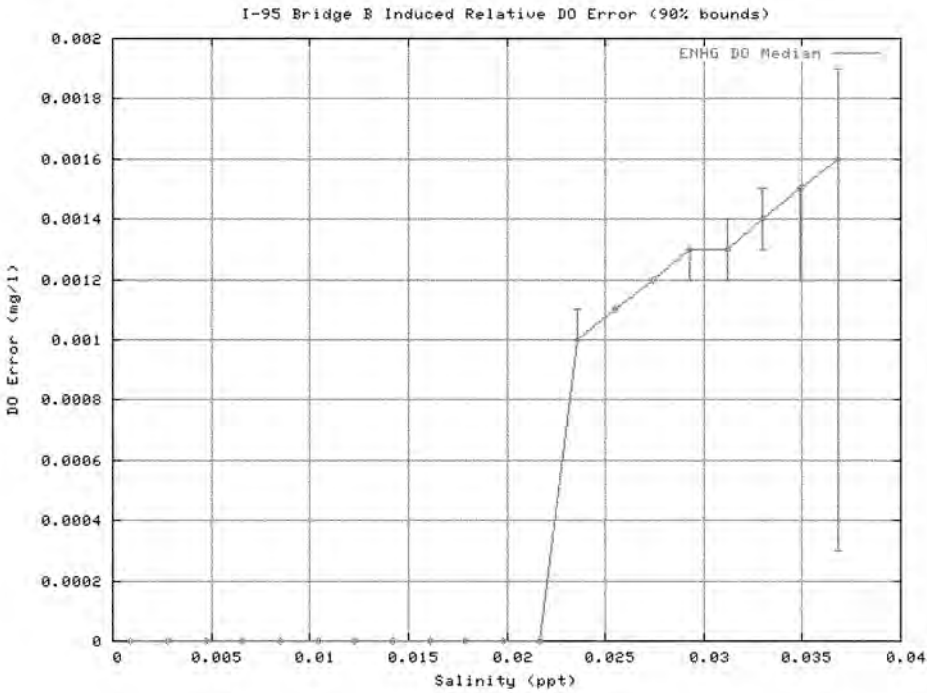


Figure 4.16: DO Relative Error Analysis, I-95 Bridge, 00-03





## Chapter 5

# Findings and Recommendations

### 5.1 Findings: Available Data

If proper caution is used there is sufficient data for the calibration and verification of hydrodynamic models of the lower Savannah River. As noted in the draft report, the restriction of detailed data to two summer periods has created a risk of overcalibration of the model to those conditions. The strong difference in performance between the 97-99 time frame and the 00-03 time frame raises this as a potential issue with the ENHG Model, although it is believed here that other factors are at work. For derived quantities such as dissolved oxygen, the acquisition of additional data would be highly desirable. In addition, secondary data such as rainfall and other meteorology could be significantly improved by incorporating data from KHXD (Hilton Head), buoy data, NEXRAD, and surface analyses.

During the evaluation process concerns were raised as to quality control and uncertainty of input data sets, especially with respect to sensor error, tides and boundary salinity. While it is dangerous to argue that a data set is flawed because it causes a model to crash, especially when other configurations do not, it is interesting to note that a modified water surface elevation file enabled the model to run the full seven year time frame. Given that a model is only as good as its input data, it is recommended that key input data bases (such as tide and salinity boundaries) be subjected to a quality control process.

### 5.2 Findings: ENHG Model

The ENHG model has the potential to be a significant improvement relative to the TMDL model. Median errors decreased at three of the four stations, and error bands decreased at all four sites in the "part A" runs (1997-1999). Improved frequency distribution estimates were noted at three sites, while at the fourth (I-95) frequency distributions were about the same. Unfortunately, neither TetraTech nor Kinetic Analysis Corporation were able to conduct a successful 7 year run of the Enhanced Grid model using observed boundary conditions. As noted above, the analyses in this report were based on two runs on

either side of a critical point at which the model became unstable. This a source of serious concern with respect to the usability of the model for predictive purposes. When the "part B" runs were assessed, median errors and error bands were significantly different than the part "A" runs. Given the different flow characteristics between the two data sets, this potentially indicates that the instability in the model is impacting uncertainty in the model across the lower range of flows. This is especially evident at the FWS (Figure 3.2) and Lucknow (Figure 3.3) sites. Note the very distinct differences in median errors, especially in the 150-250 cubic meters per second bands which comprise over 40 percent of flows during the study period. These differences potentially indicate problems with the geometry of the back river or marsh depiction. The graphs in chapter 14 contain plots showing error by phase of the tide cycle. It is interesting to note that the model has higher errors in the outgoing phase of the tide cycle than on the inbound phase. One potential source of this phenomena is marsh depiction and storage, although there are many other possibilities, including bottom roughness, channel geometry, bathymetry, and so forth.

### 5.3 Recommendations

The primary issue found by KAC is the inability of the model to complete a seven year simulation. This restricted our ability to fully assess the uncertainty in the model in a similar fashion to the TMDL model. Therefore, KAC does not recommend the use of the ENHG model for primary decision making until such time as the source of the instability can be properly diagnosed, corrected, and a continuous seven year run can be conducted. The preferred, and recommended, approach is to continue development work on the model to create a configuration that can complete a seven year run without aborting. Otherwise, doubts will remain as to the stability of the model. An alternative is to conduct a series of runs at different step sizes and channel geometries to ensure that the model is stable throughout the range of intended uses during the calibration/verification period. These runs should be compared to similar TMDL model runs to ensure the ENHG results are rational.

Additional specific recommendations:

- 1) Version control should be implemented for both source code and input files;
- 2) The model should complete a 7 year run using scientifically defensible boundary conditions and channel configuration, or, sufficient simulations with projected bathymetry should be conducted with varying time steps and analyzed to ensure model stability;
- 3) Assess the potential to promote all floating point variables from "real" to "double precision", respecting the possibility that this may introduce unacceptable noise in the numerical solutions;
- 4) Assess boundary conditions, bottom friction, and geometry, especially in the upper and back rivers, to ensure the geometry is not introducing noise into the solutions;
- 5) Evaluate marsh depiction, especially with respect to storage and release;
- 6) Additional quality control, and perhaps a formal uncertainty assessment, should be done on the input data sets. The water surface elevation/tide data should be a special

### 5.3. *RECOMMENDATIONS*

35

focus.



## **Part II**

# **Supporting Graphics**



# Chapter 6

## Houlihan Bridge A 97-99 ENHG Model

These plots show the results of the 1997-1999 simulations (part "A").

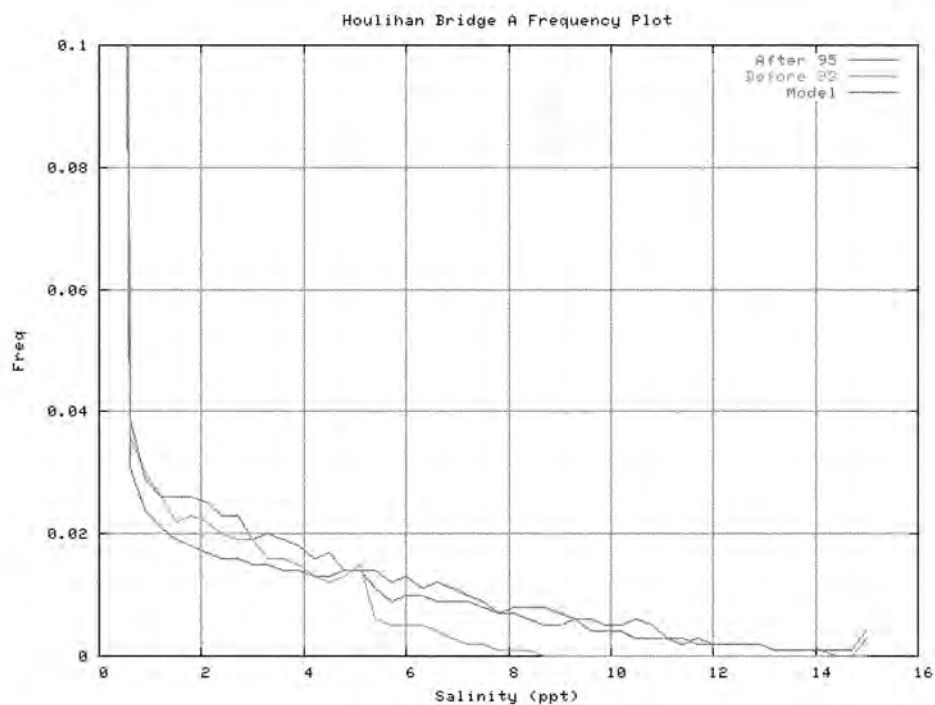


Figure 6.1: Salinity by Frequency of Occurrence

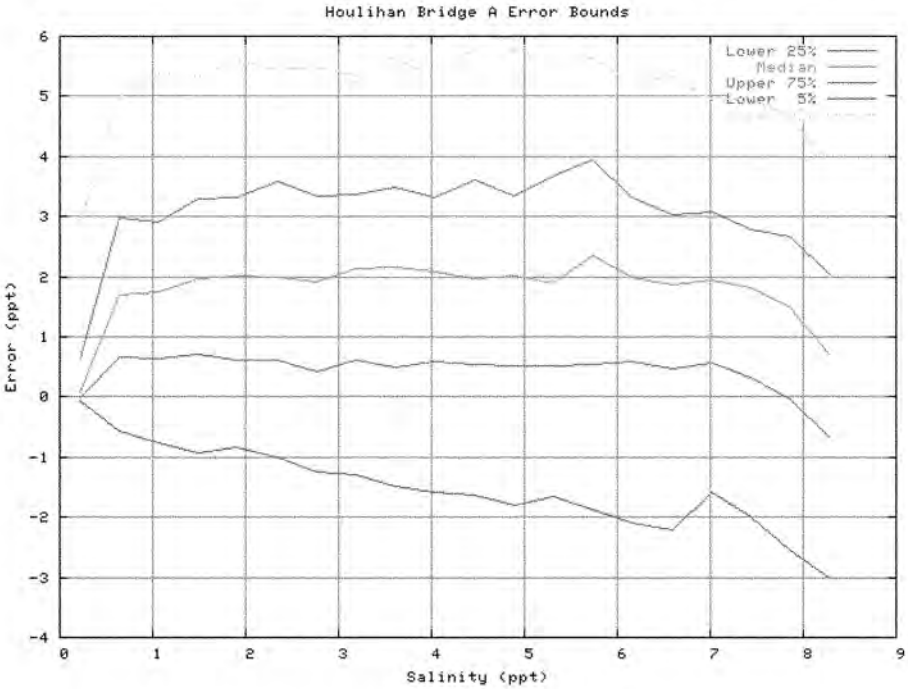


Figure 6.2: Error bounds by Salinity



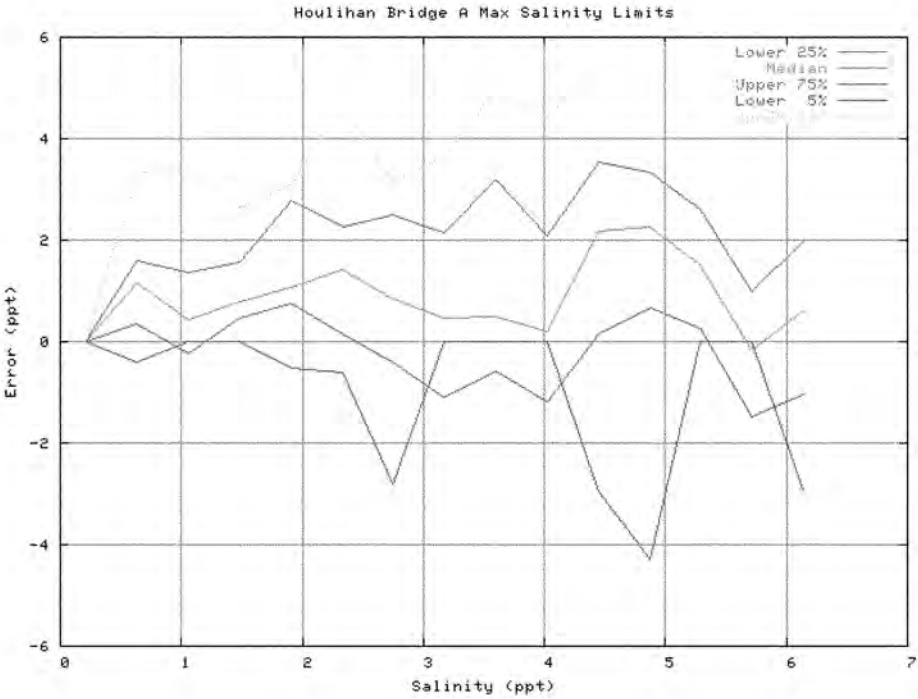


Figure 6.3: Daily Maximum Limits

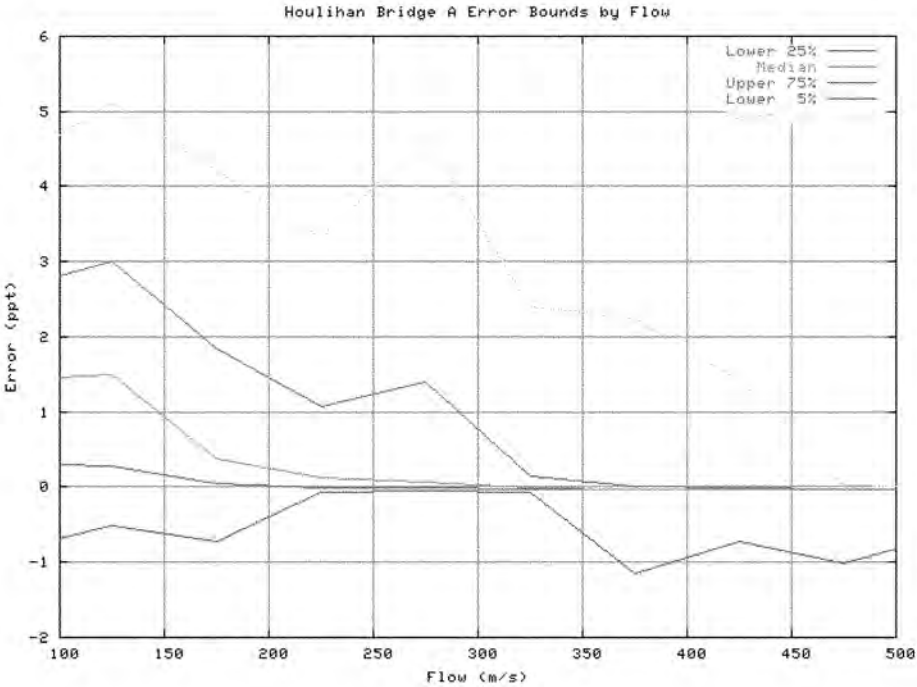


Figure 6.4: Error bounds by flow at Clyo

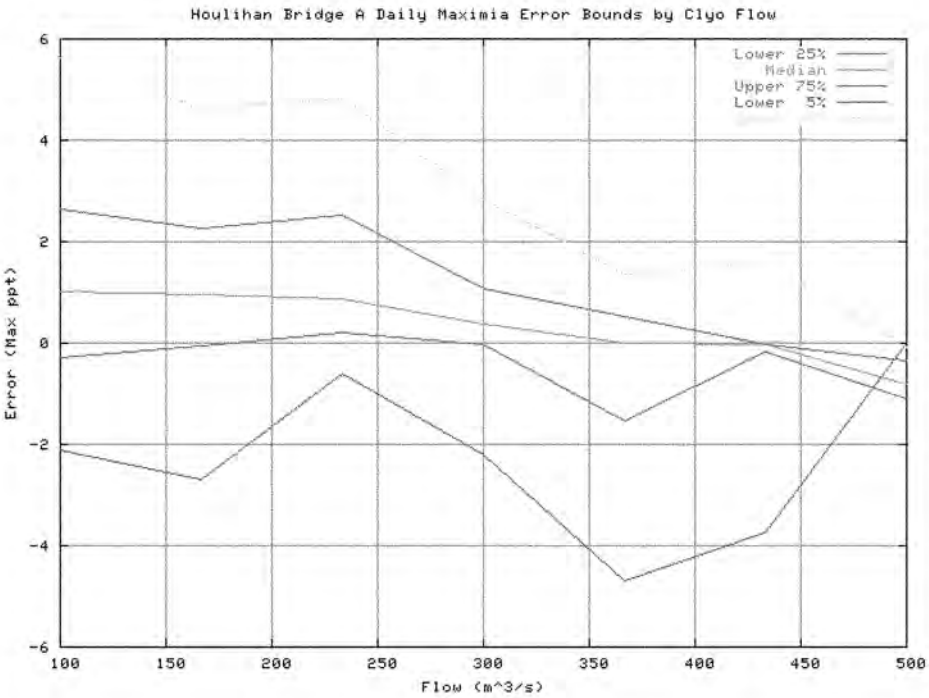


Figure 6.5: Daily Maxima error bounds by flow at Clio



# Chapter 7

## Houlihan Bridge B 00-03 ENHG Model

These plots show the results of the 2000-2003 simulations (part "B").

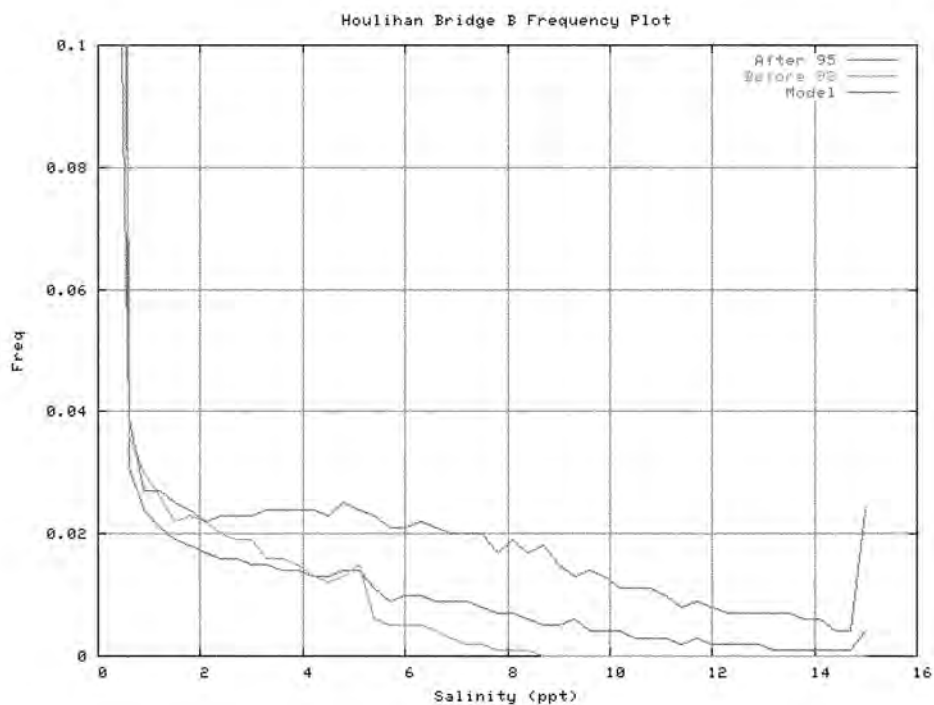


Figure 7.1: Salinity by Frequency of Occurrence

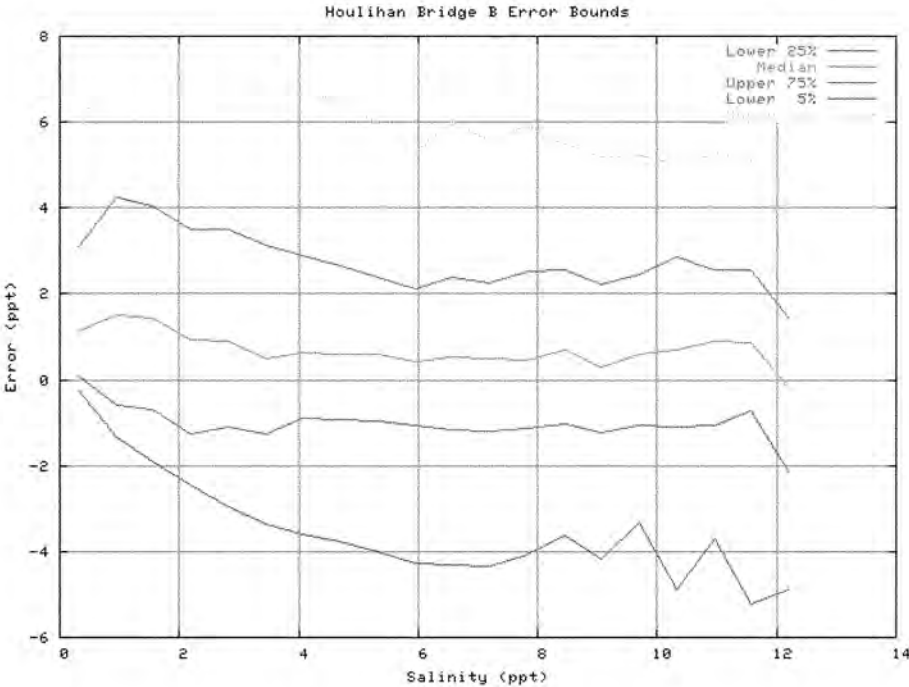


Figure 7.2: Error bounds by Salinity

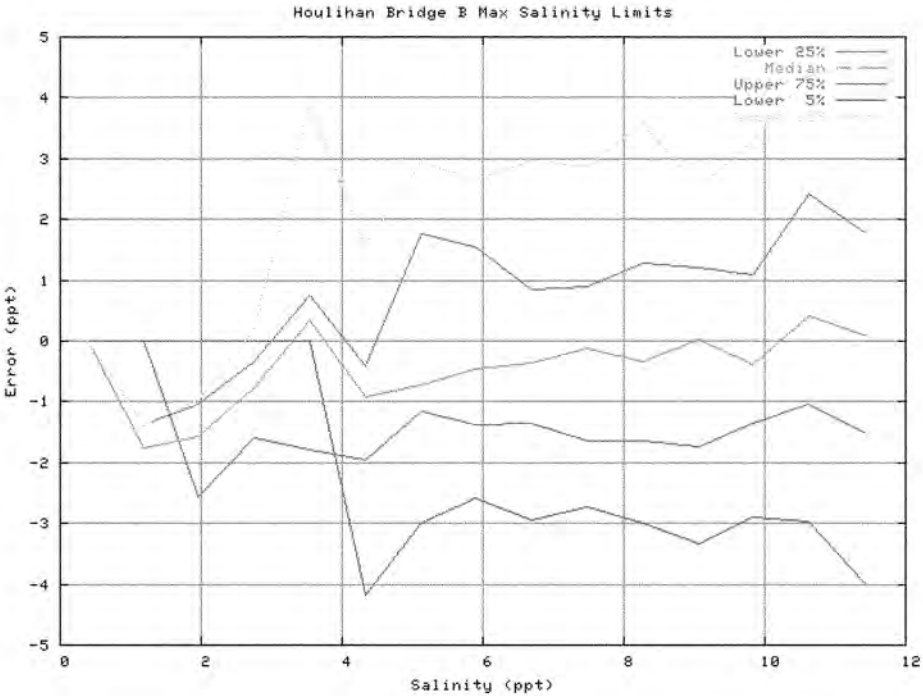


Figure 7.3: Daily Maximum Limits

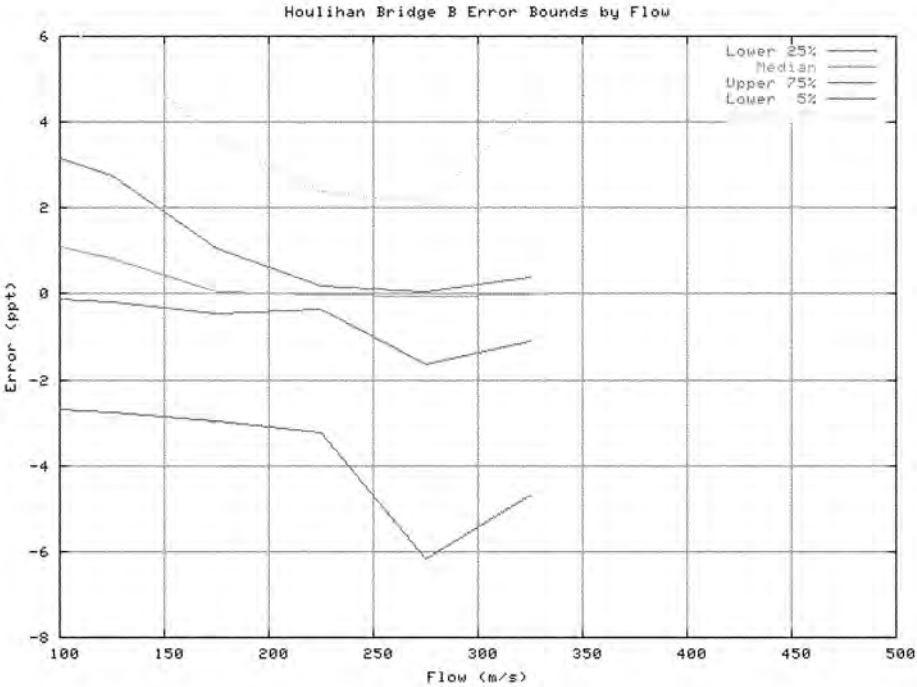


Figure 7.4: Error bounds by flow at Clyo



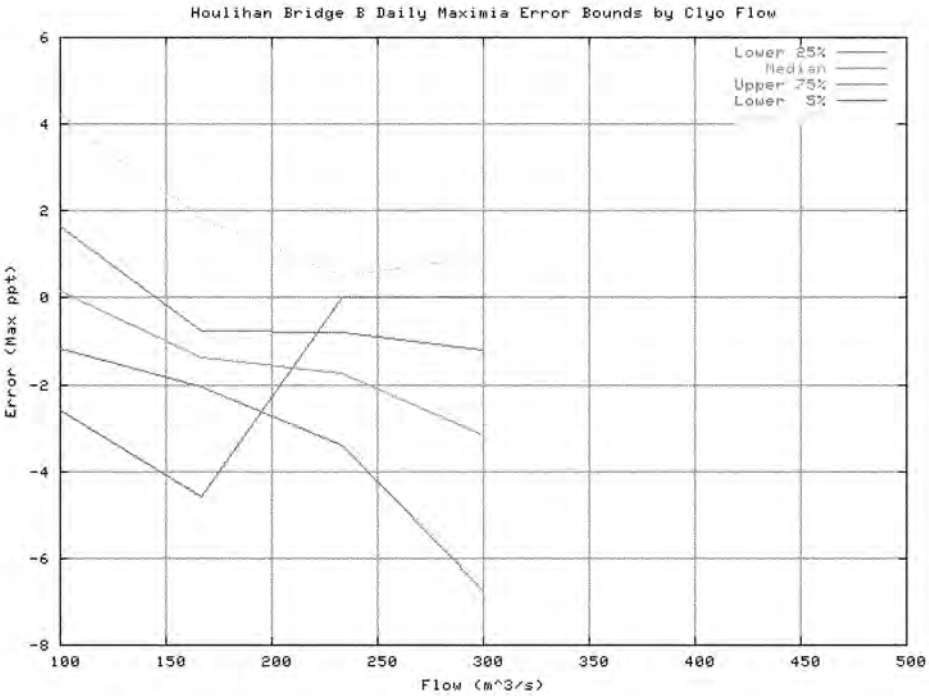


Figure 7.5: Daily Maxima error bounds by flow at Clio



## Chapter 8

### US FWS Dock A 97-99 ENHG Model

These plots show the results of the 1997-1999 simulations (part "A").

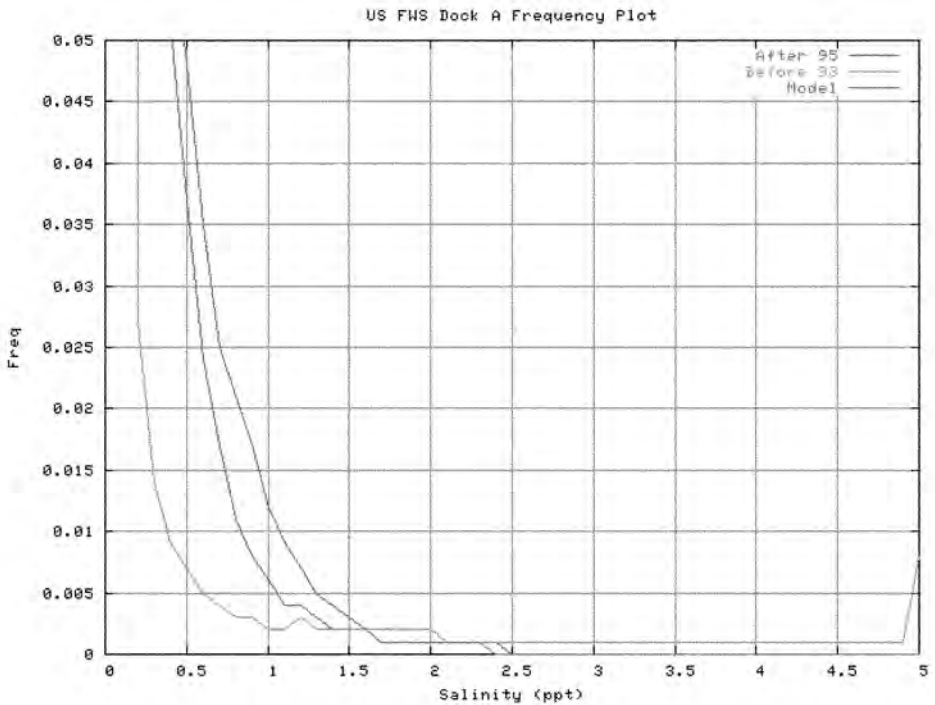


Figure 8.1: Salinity by Frequency of Occurrence

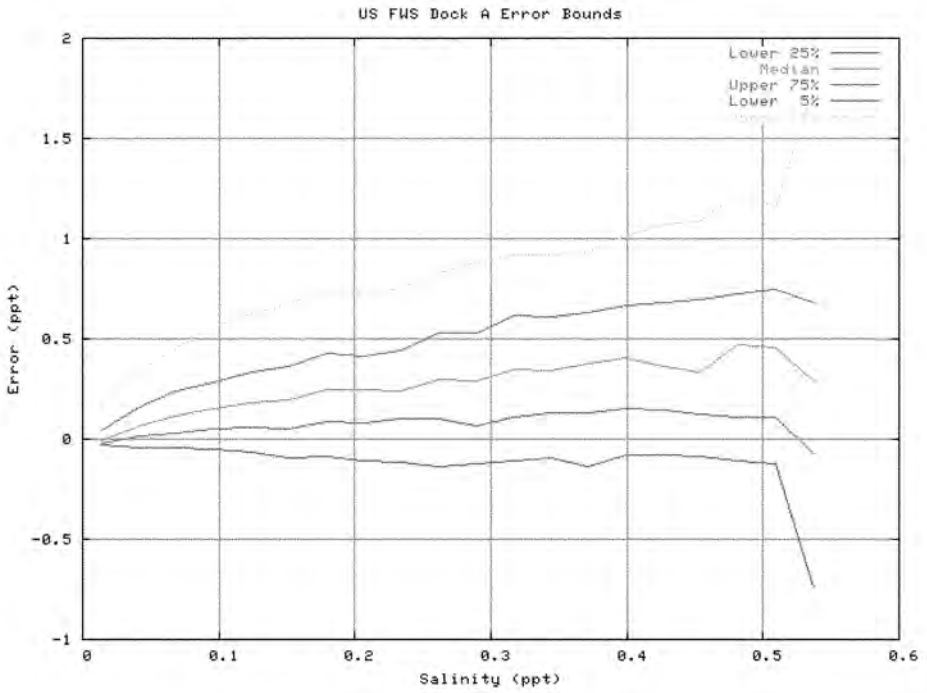


Figure 8.2: Error bounds by Salinity

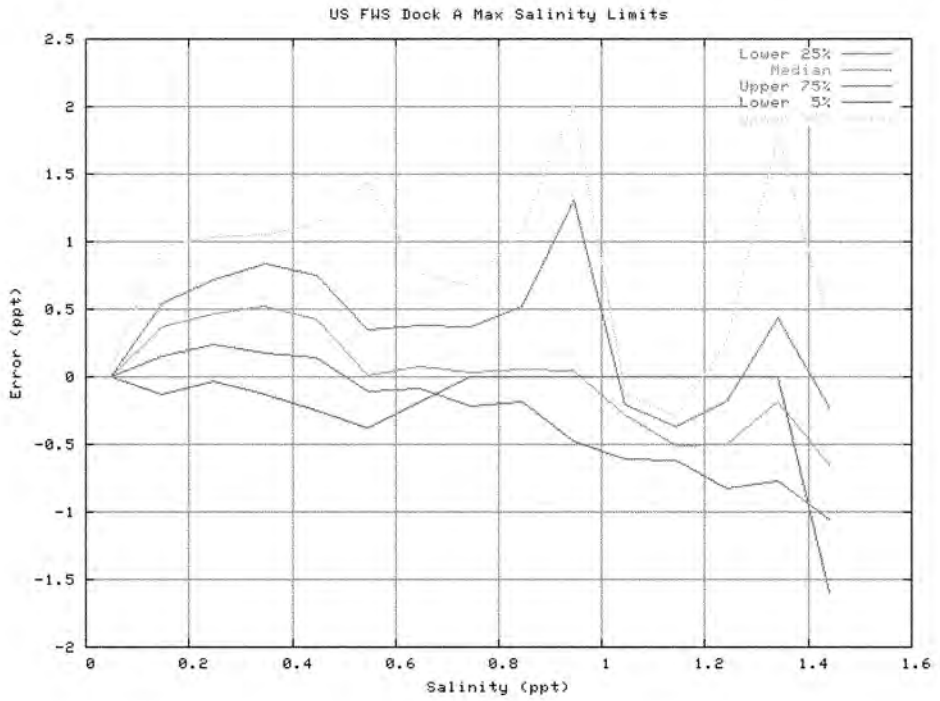


Figure 8.3: Daily Maximum Limits

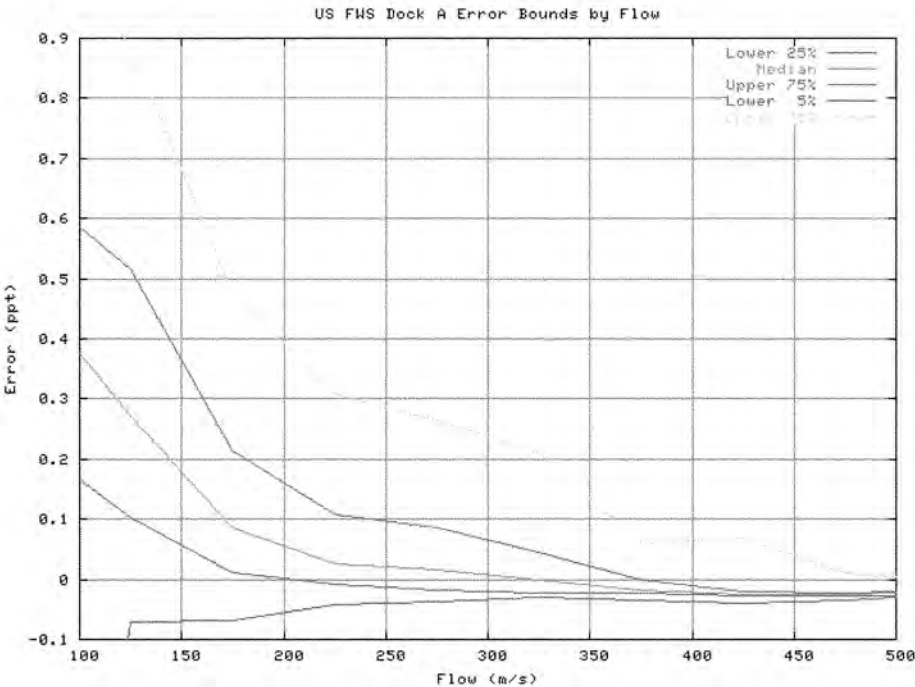


Figure 8.4: Error bounds by flow at Clyo

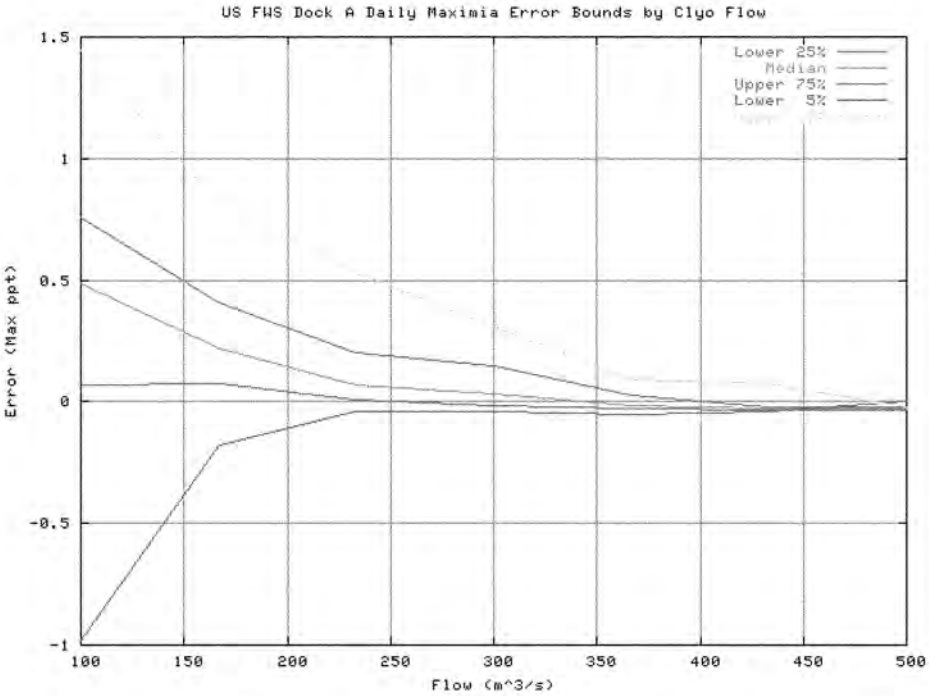


Figure 8.5: Daily Maxima error bounds by flow at Clio





# Chapter 9

## US FWS Dock B 00-03 ENHG Model

These plots show the results of the 2000-2003 simulations (part "B").

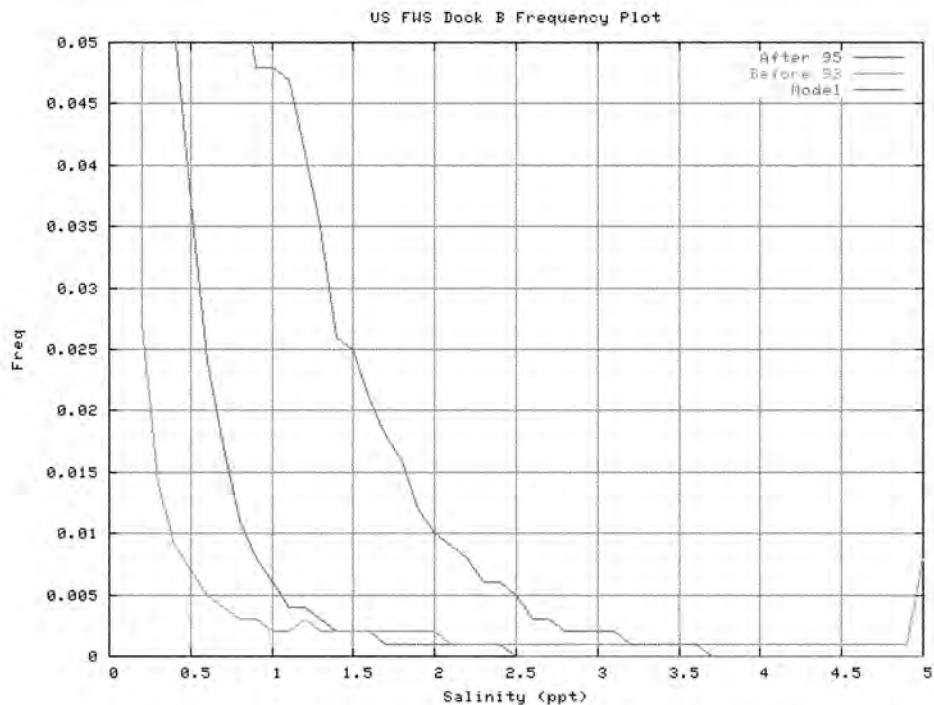


Figure 9.1: Salinity by Frequency of Occurrence

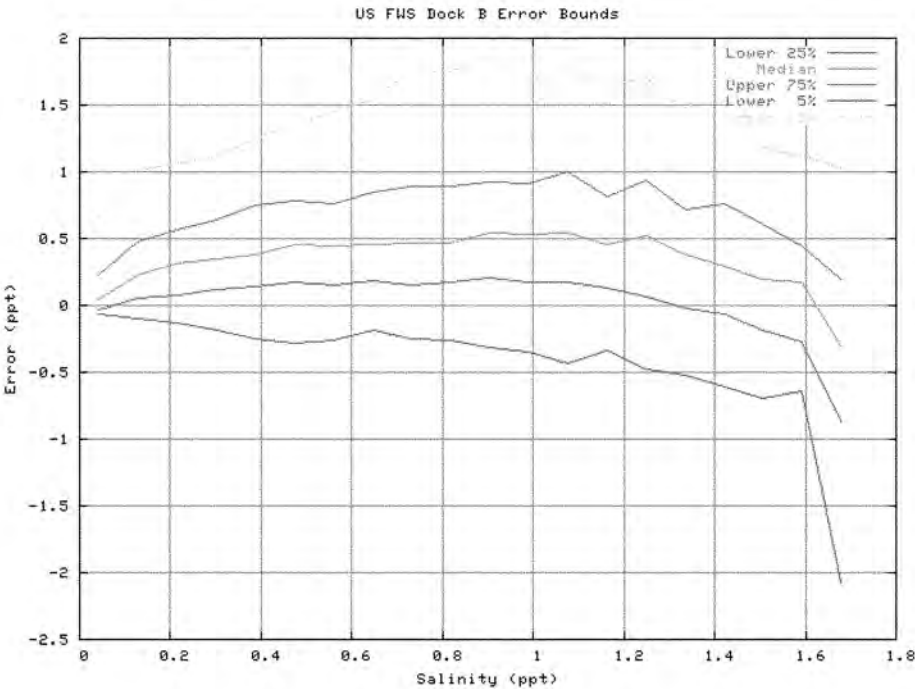


Figure 9.2: Error bounds by Salinity

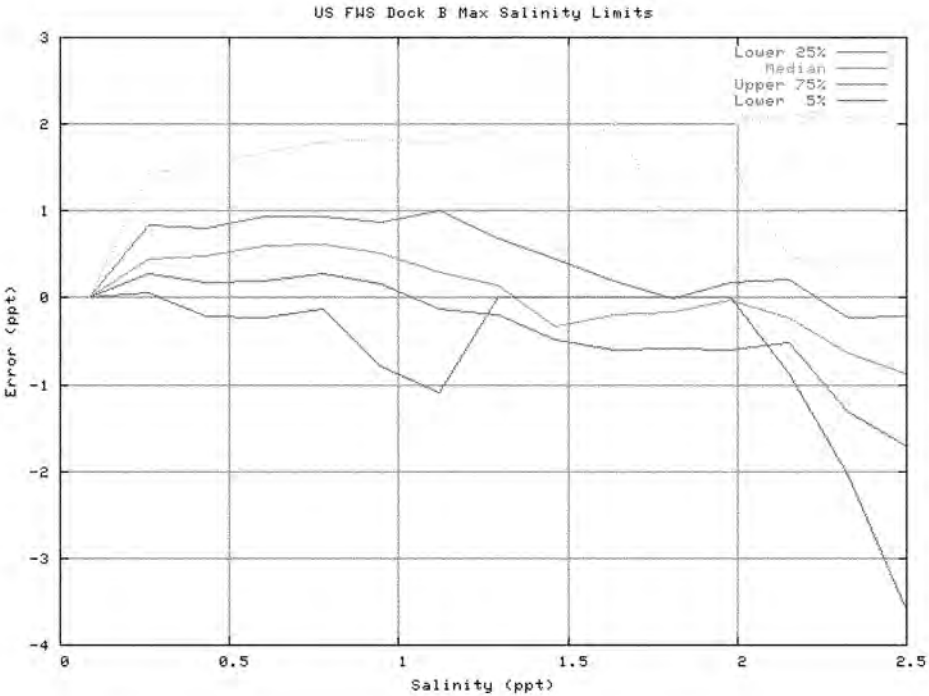


Figure 9.3: Daily Maximum Limits

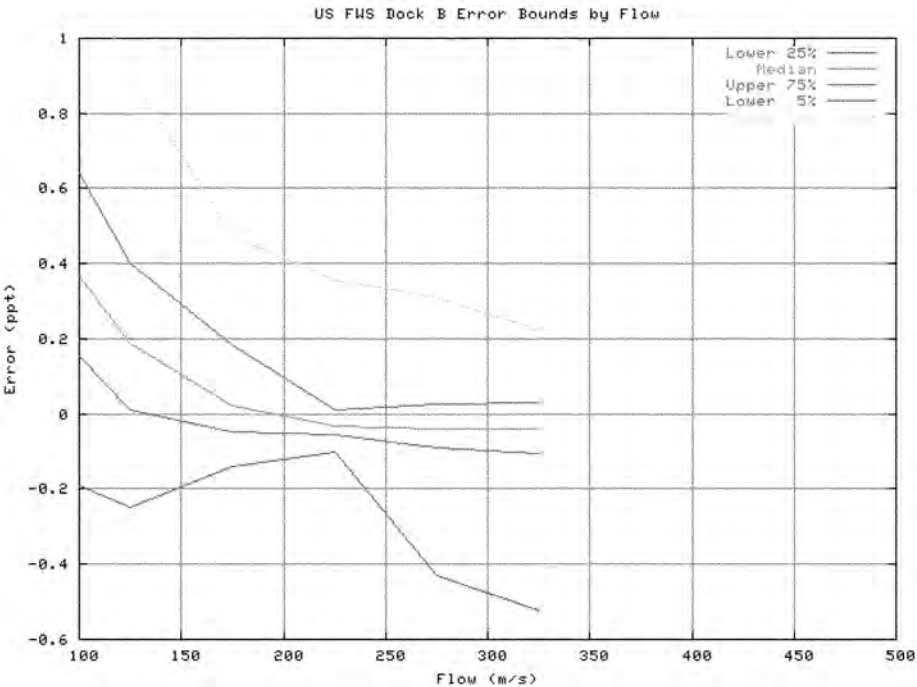


Figure 9.4: Error bounds by flow at Clyo

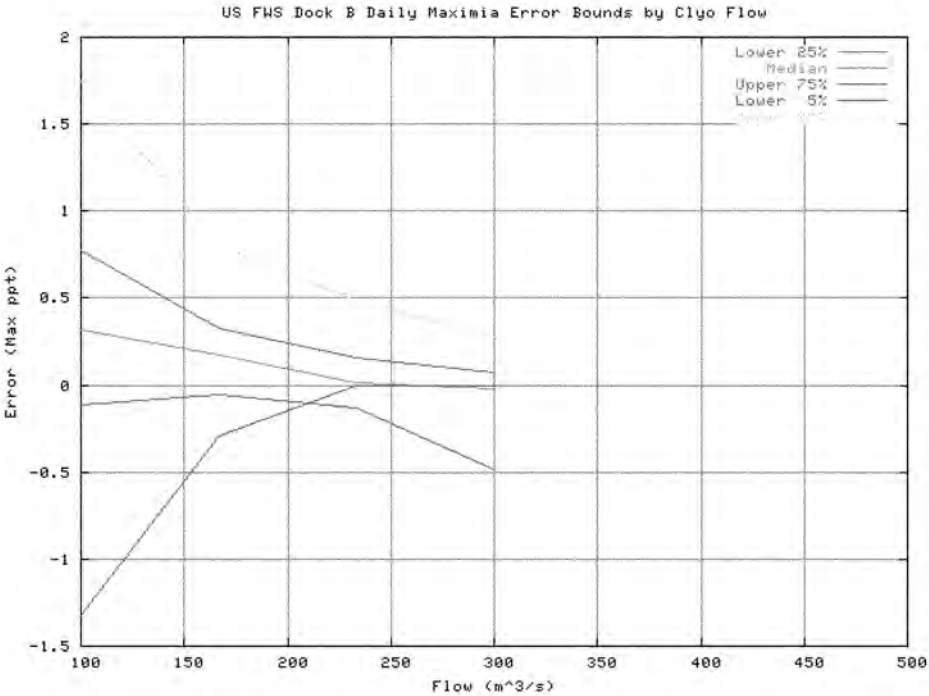


Figure 9.5: Daily Maxima error bounds by flow at Clio



# Chapter 10

## Lucknow Canal A 97-99ENHG Model

These plots show the results of the 1997-1999 simulations (part "A").

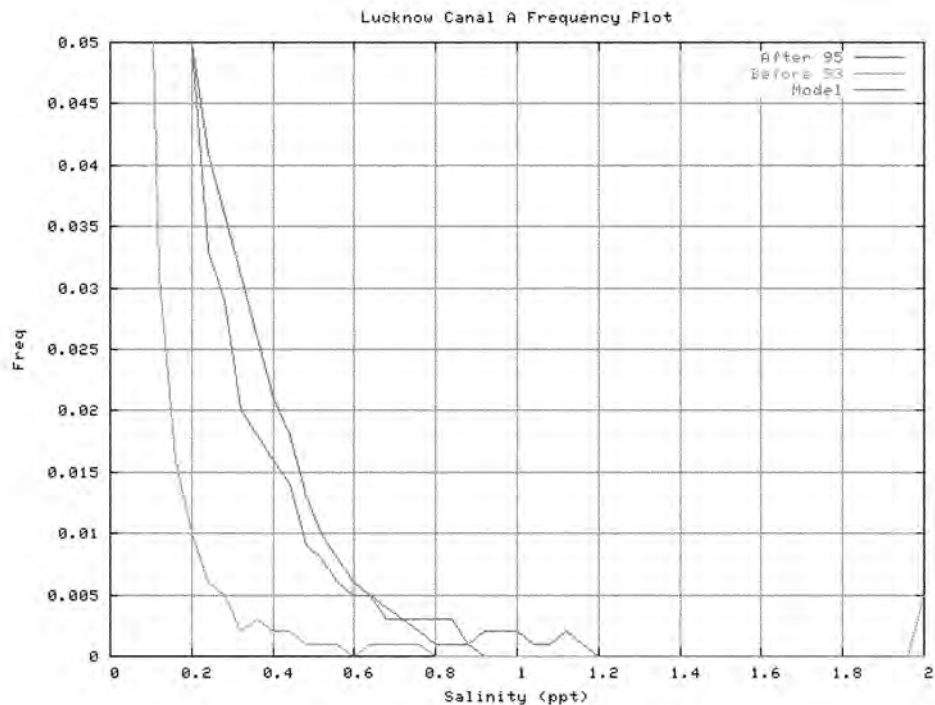


Figure 10.1: Salinity by Frequency of Occurrence

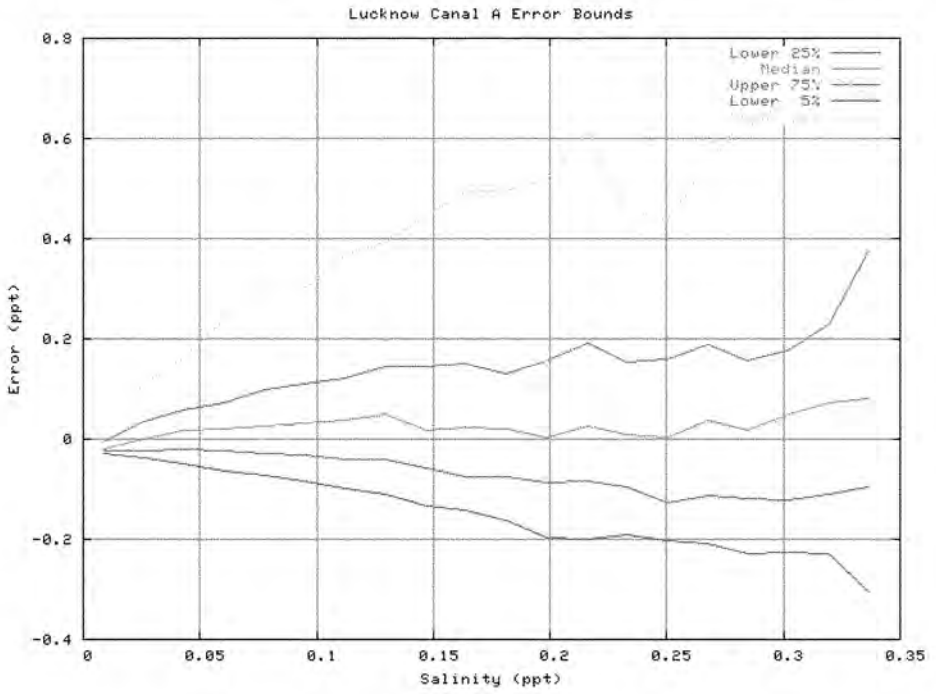


Figure 10.2: Error bounds by Salinity



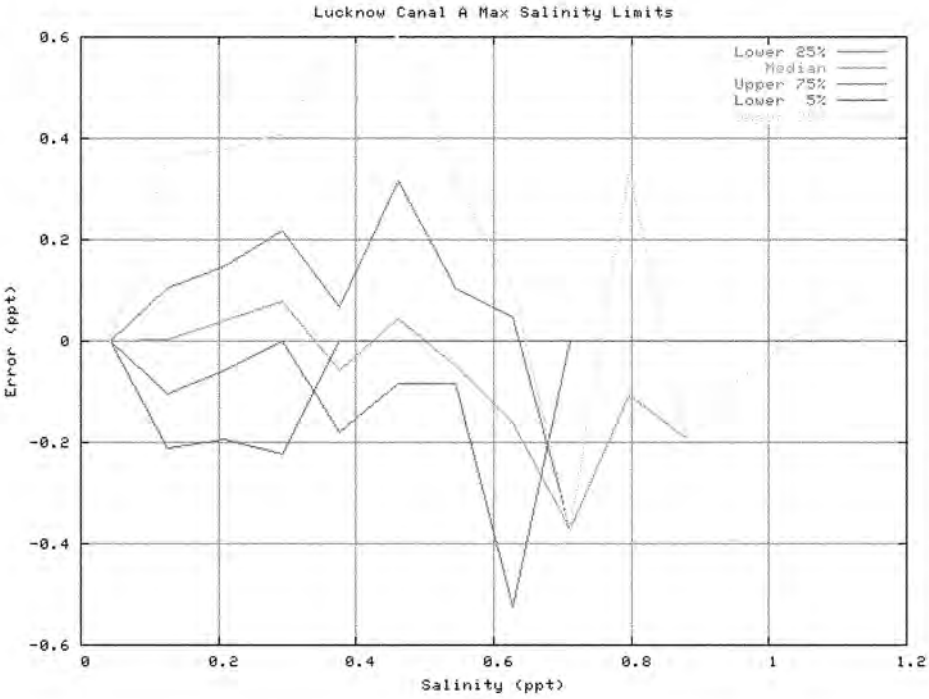


Figure 10.3: Daily Maximum Limits

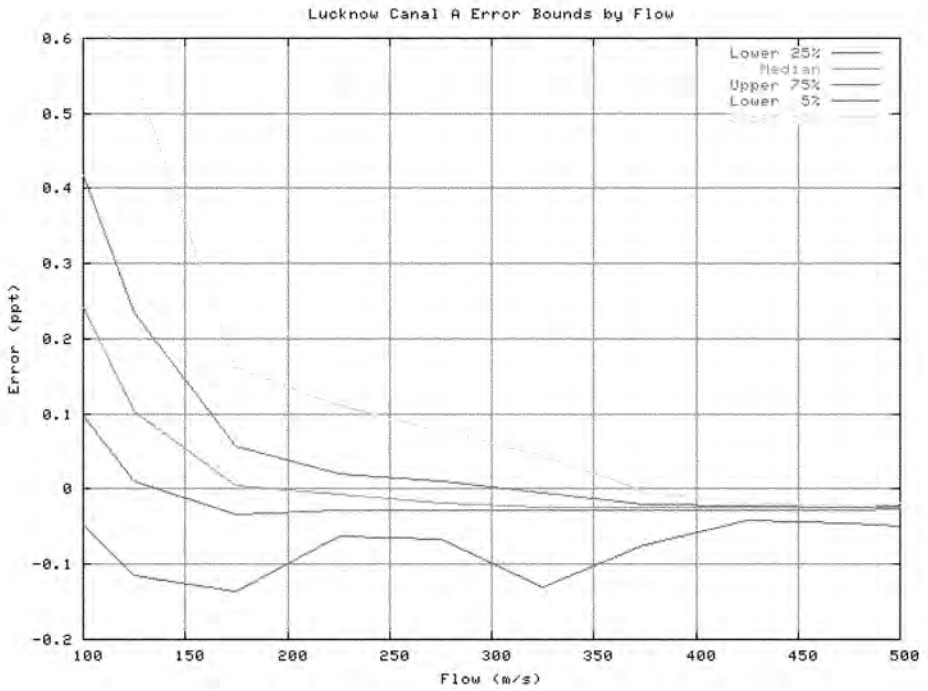


Figure 10.4: Error bounds by flow at Clyo

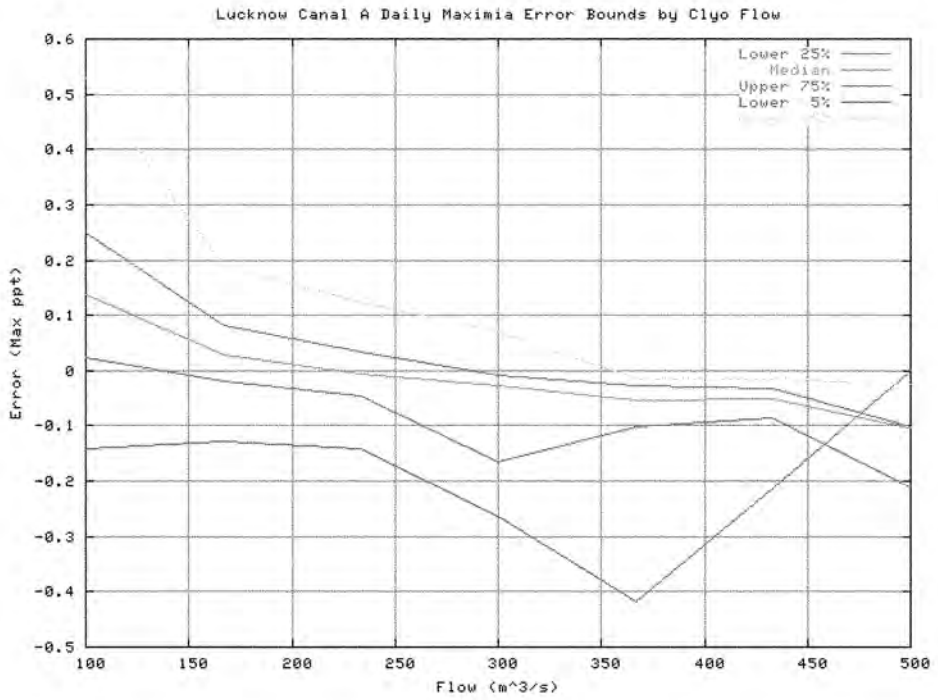


Figure 10.5: Daily Maxima error bounds by flow at Clyo



# Chapter 11

## Lucknow Canal B 00-03 ENHG Model

These plots show the results of the 2000-2003 simulations (part "B").

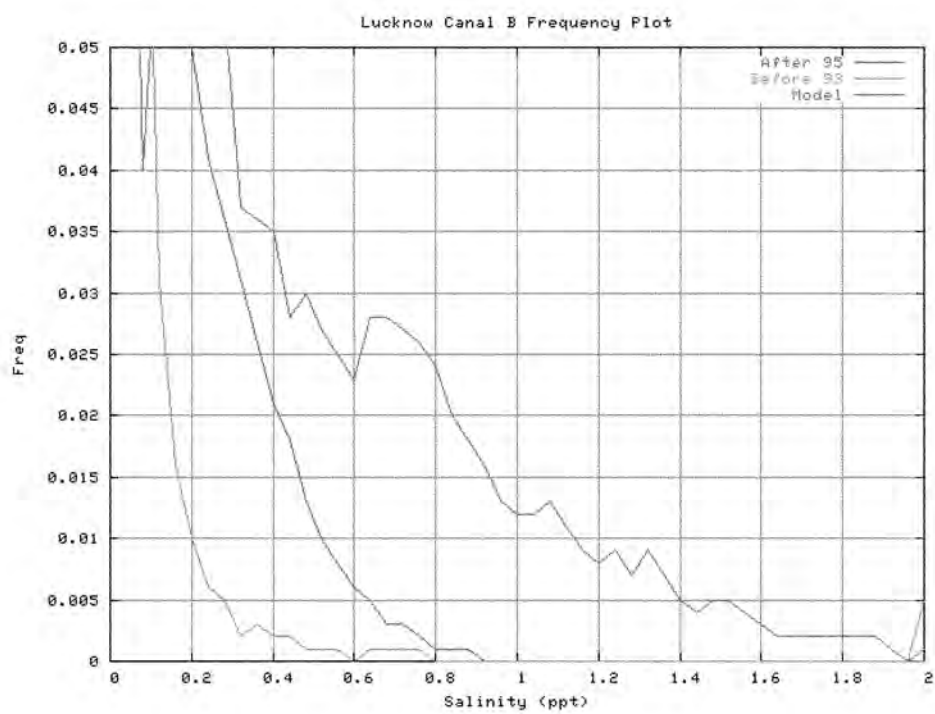


Figure 11.1: Salinity by Frequency of Occurrence

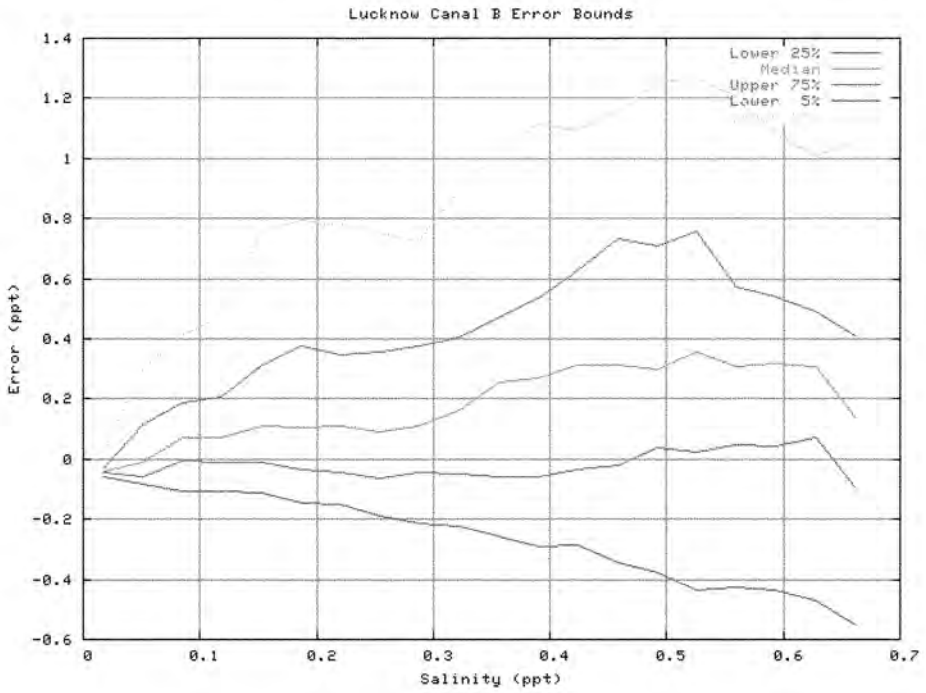


Figure 11.2: Error bounds by Salinity

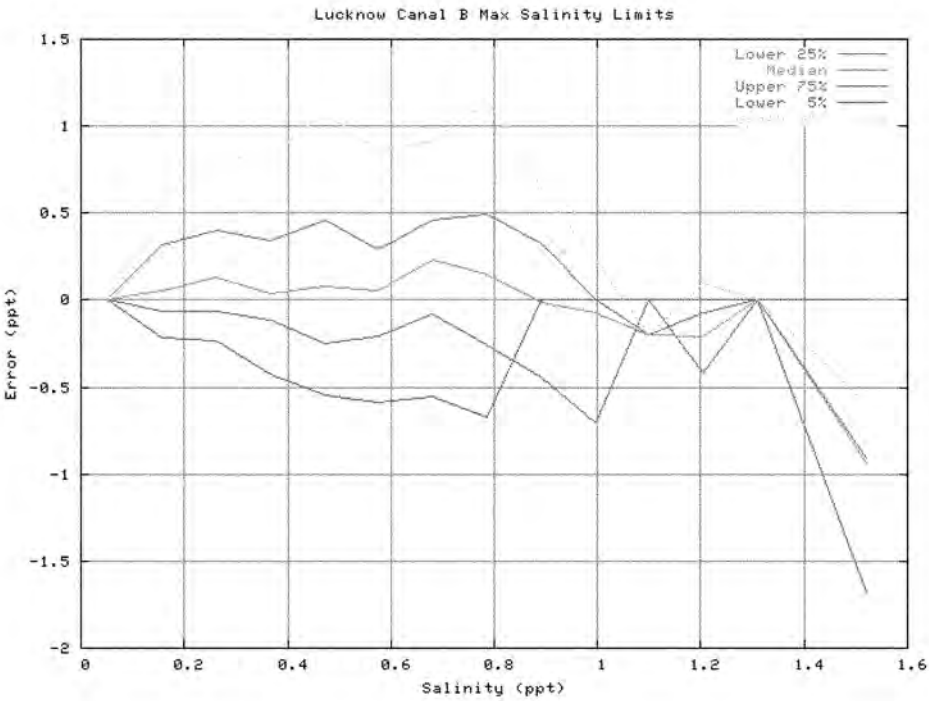


Figure 11.3: Daily Maximum Limits

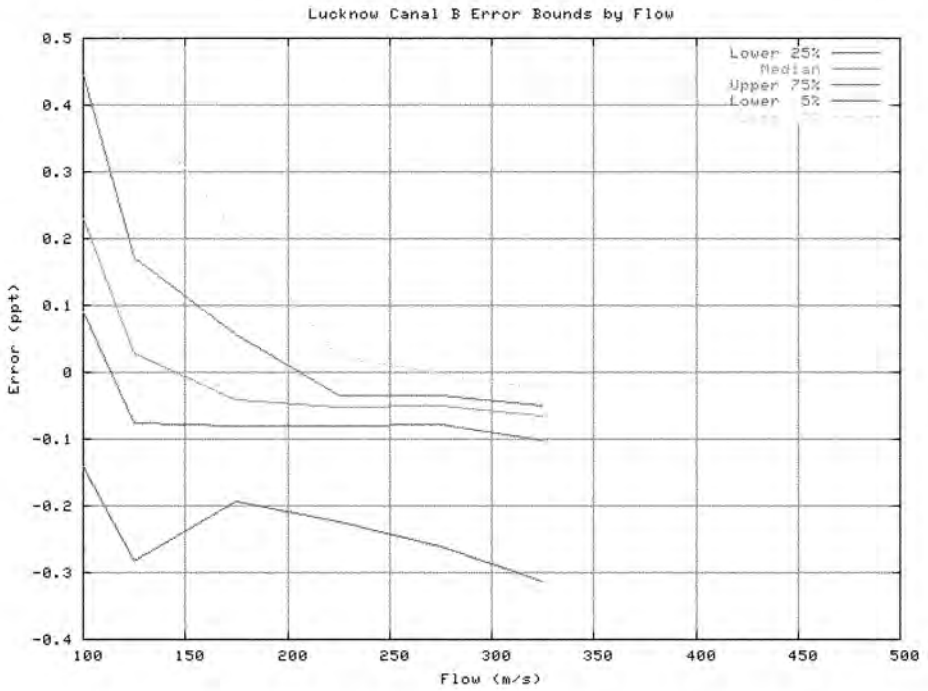


Figure 11.4: Error bounds by flow at Clyo



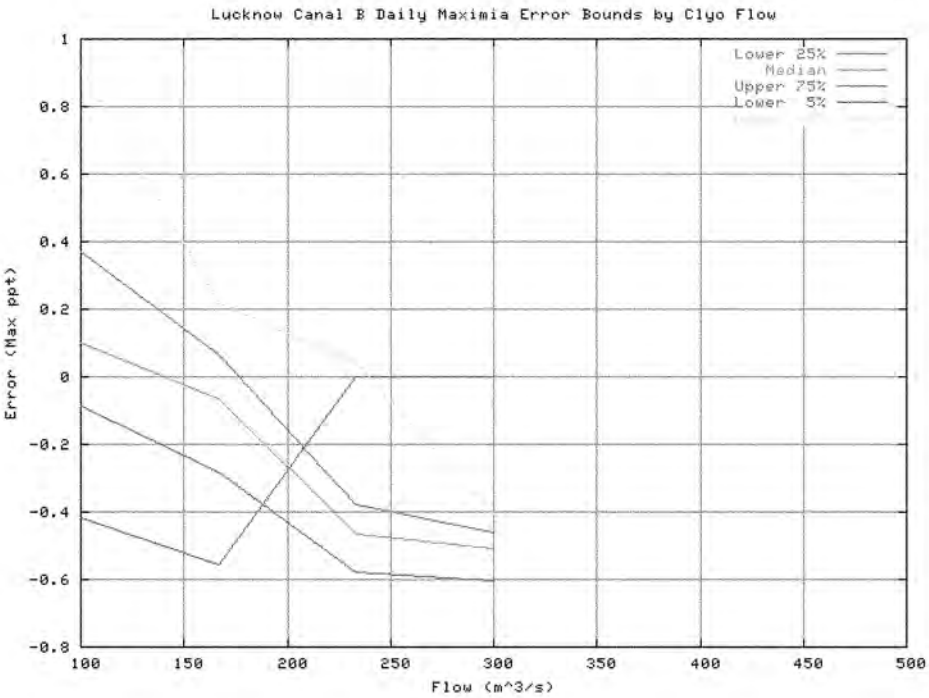


Figure 11.5: Daily Maxima error bounds by flow at Clio



# Chapter 12

## I-95 Bridge A 97-99 ENHG Model

These plots show the results of the 1997-1999 simulations (part "A").

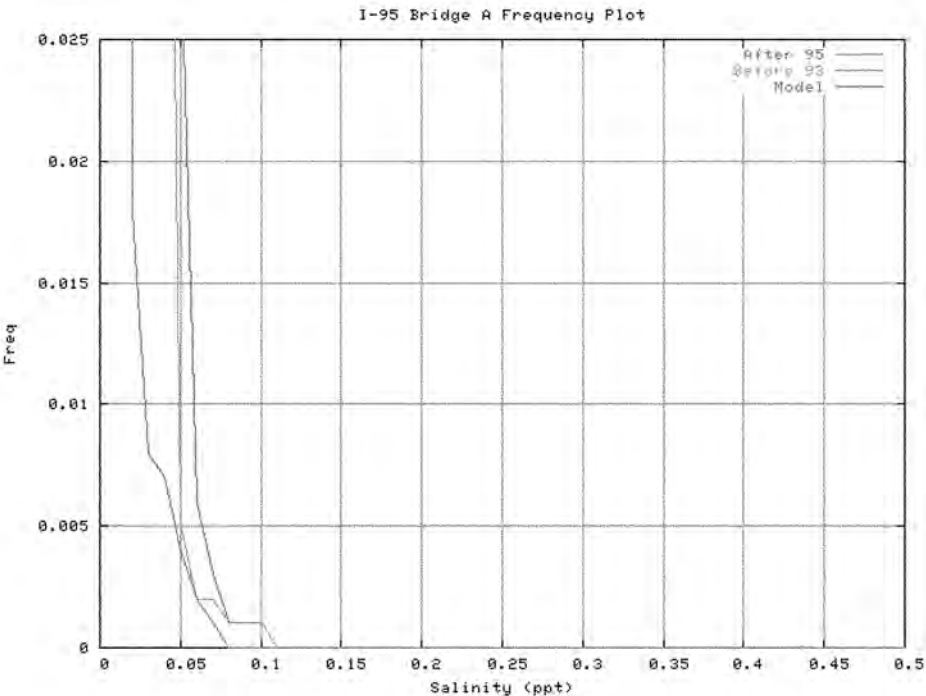


Figure 12.1: Salinity by Frequency of Occurrence

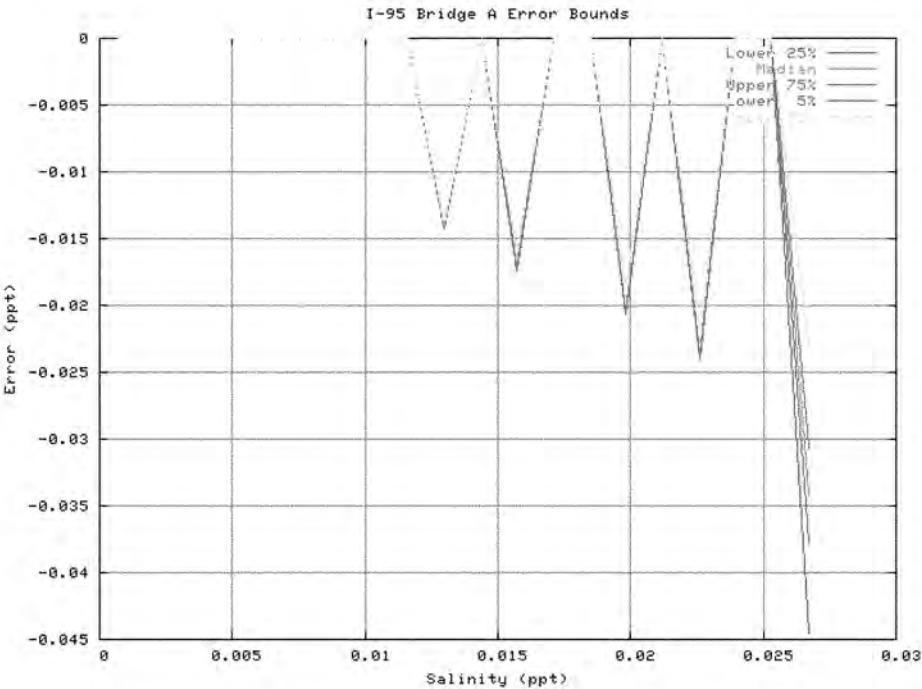


Figure 12.2: Error bounds by Salinity

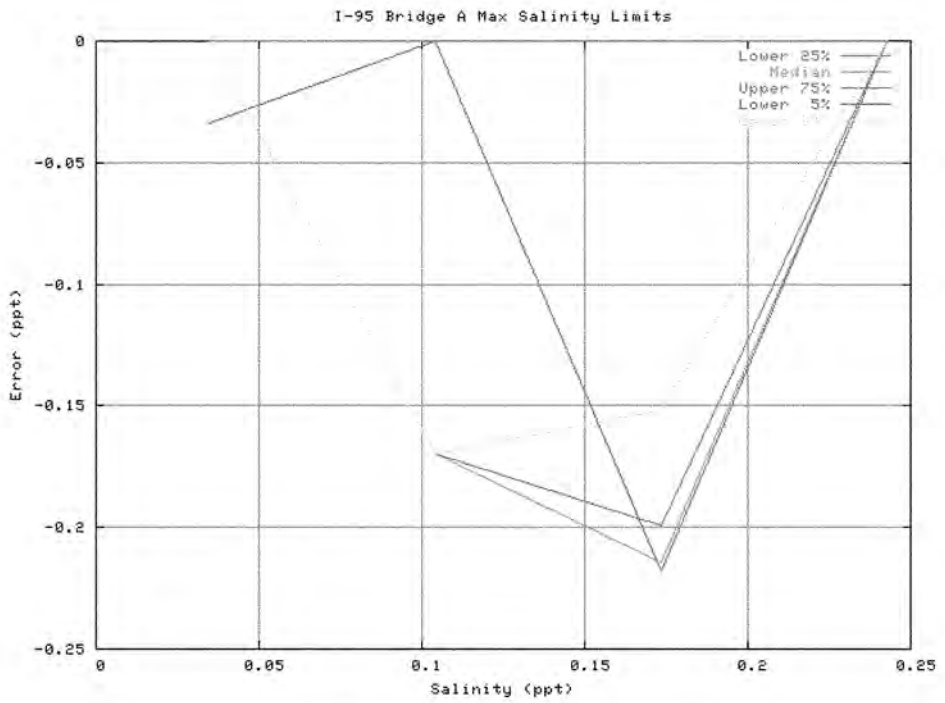


Figure 12.3: Daily Maximum Limits

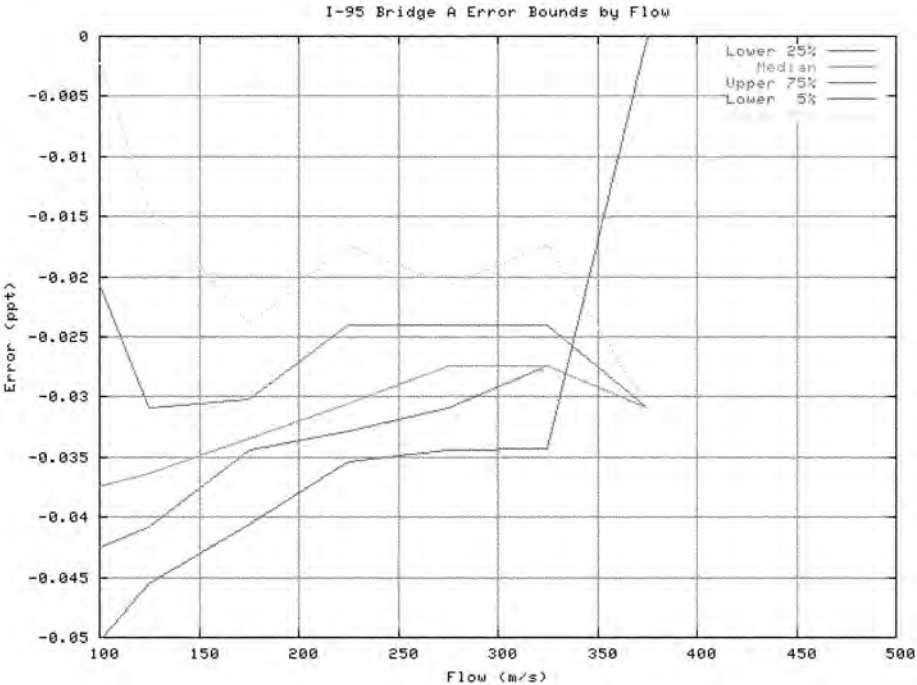


Figure 12.4: Error bounds by flow at Clyo

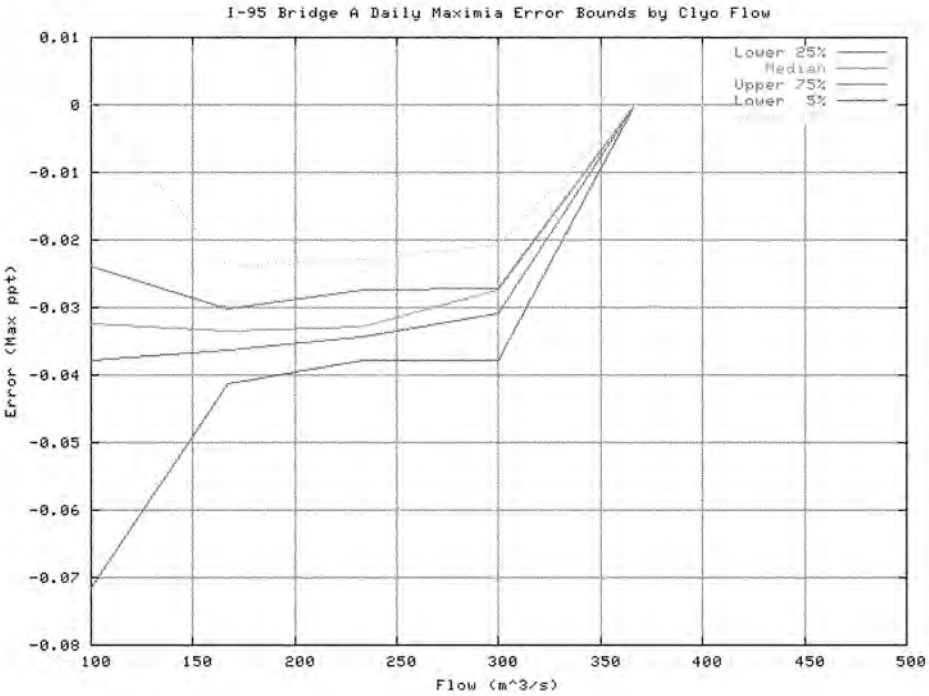


Figure 12.5: Daily Maxima error bounds by flow at Clio





# Chapter 13

## I-95 Bridge B 00-03 ENHG Model

These plots show the results of the 2000-2003 simulations (part "B").

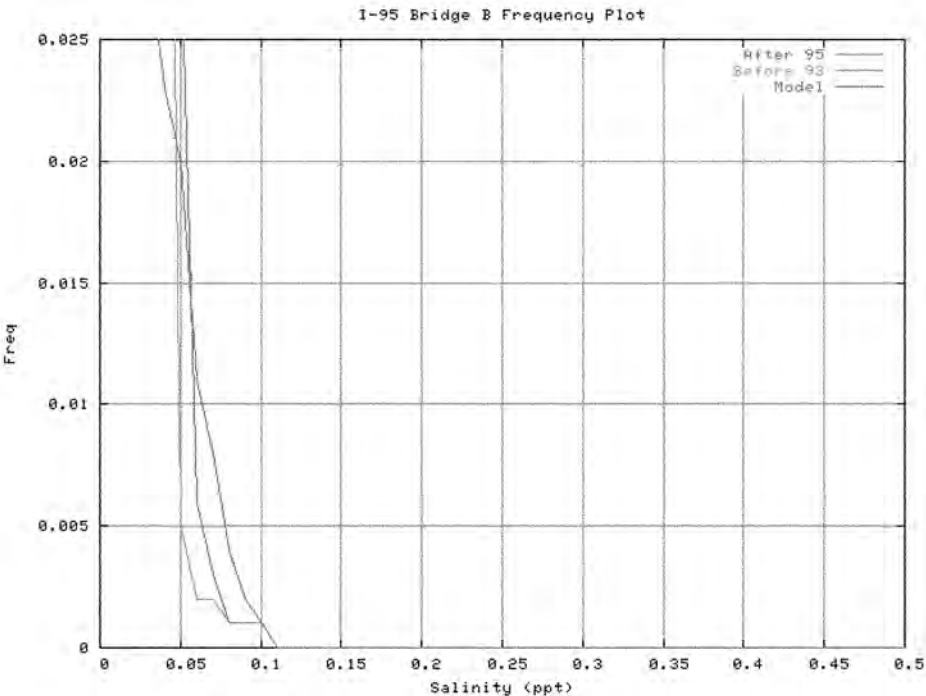


Figure 13.1: Salinity by Frequency of Occurrence

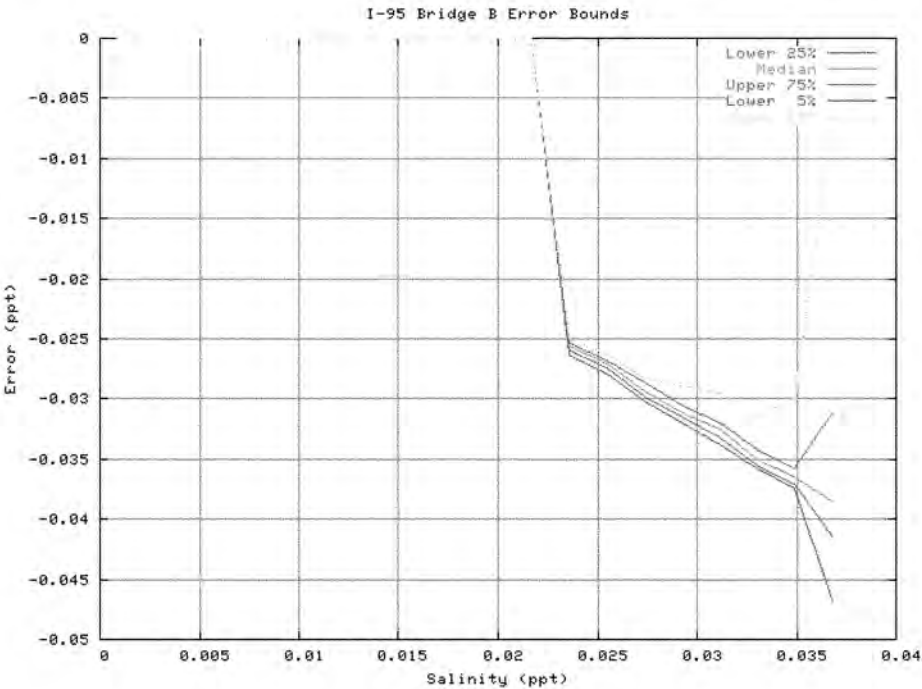


Figure 13.2: Error bounds by Salinity

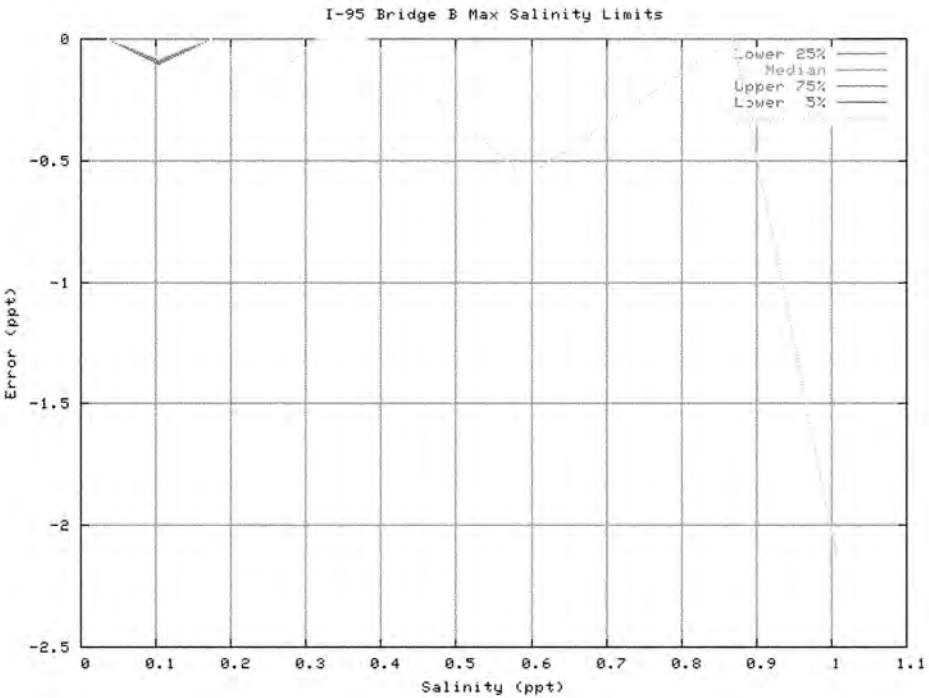


Figure 13.3: Daily Maximum Limits

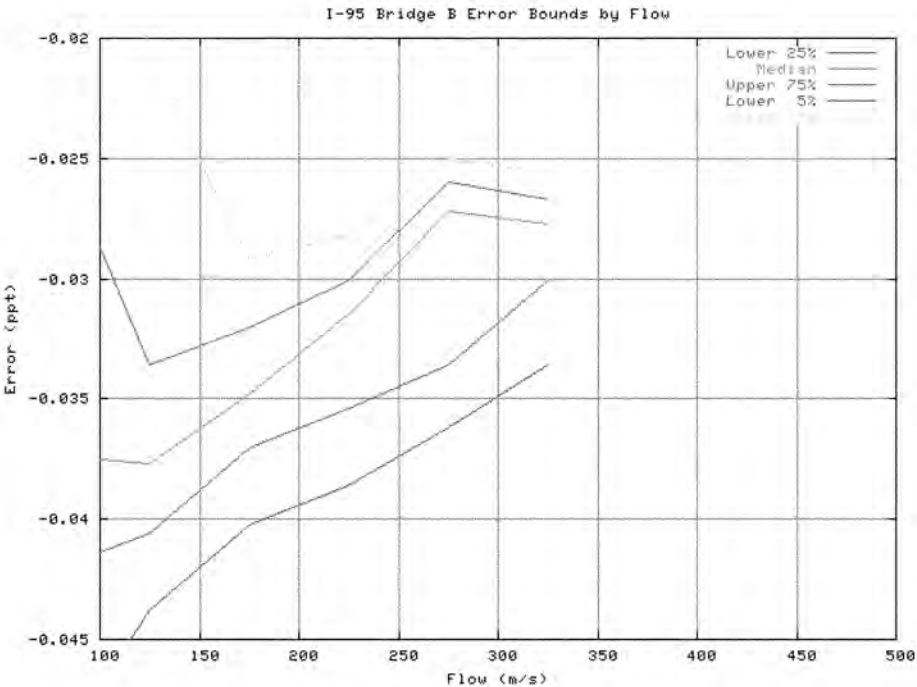


Figure 13.4: Error bounds by flow at Clyo

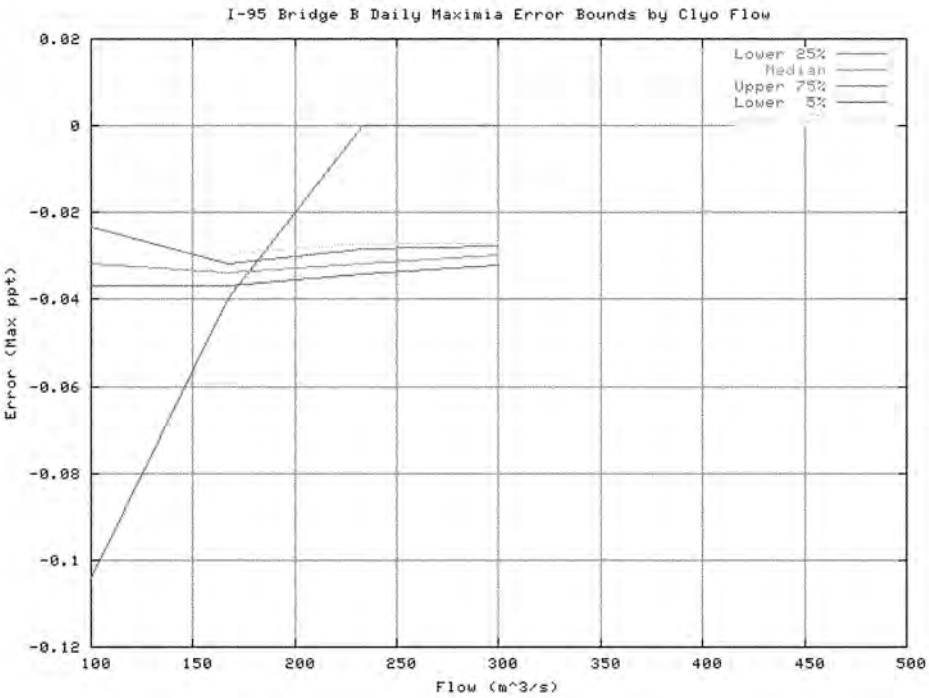


Figure 13.5: Daily Maxima error bounds by flow at Clio



## Chapter 14

### Error by phase of tide cycle

One indication of the performance and sensitivity of the model is to display error by tide. The graphs below plot the error in salinity in terms of the magnitude and phase (incoming or outgoing) of the tide.

## 14.1 Performance on 1997-1999 run

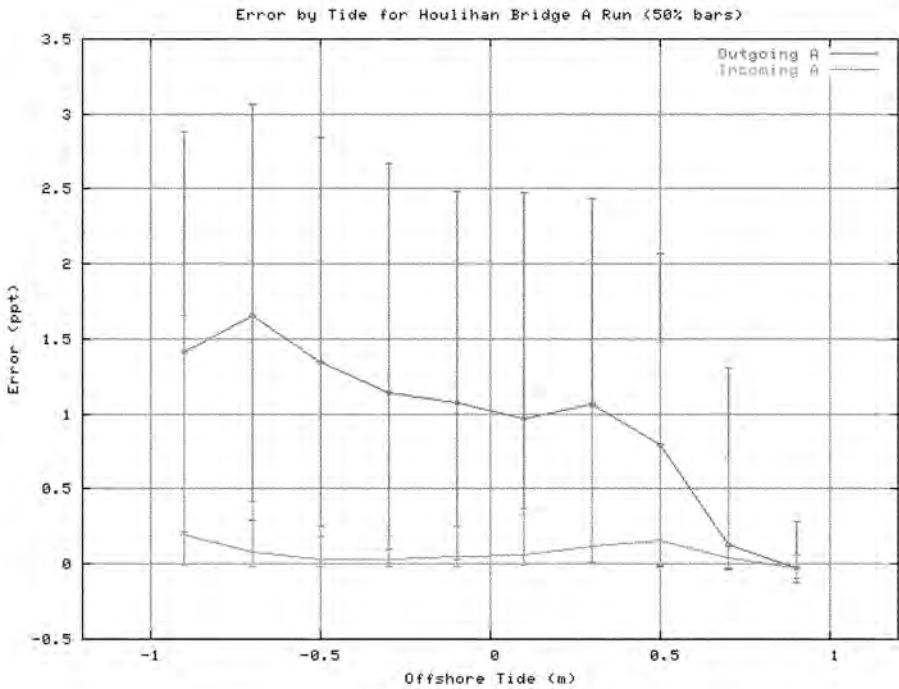


Figure 14.1: Error by tide, Houlihan Bridge, 97-99



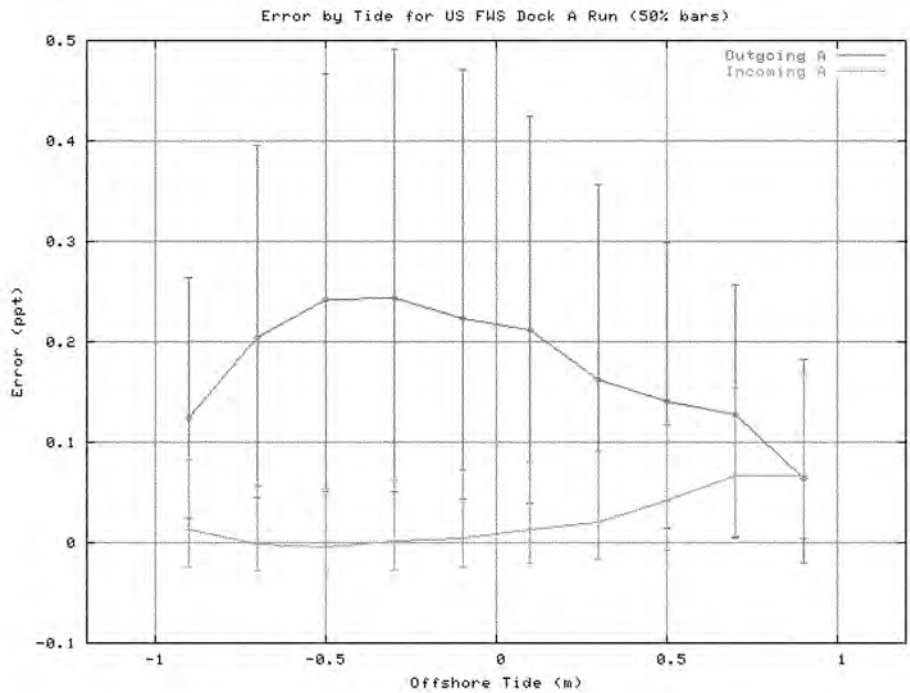


Figure 14.2: Error by tide, USFWS Dock, 97-99

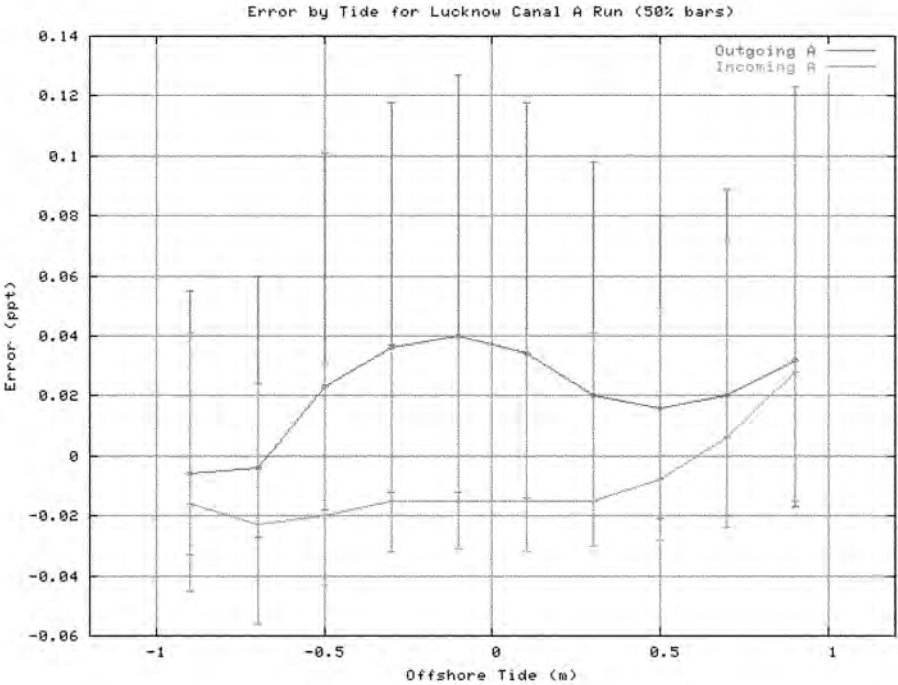


Figure 14.3: Error by tide, Lucknow Canal, 97-99

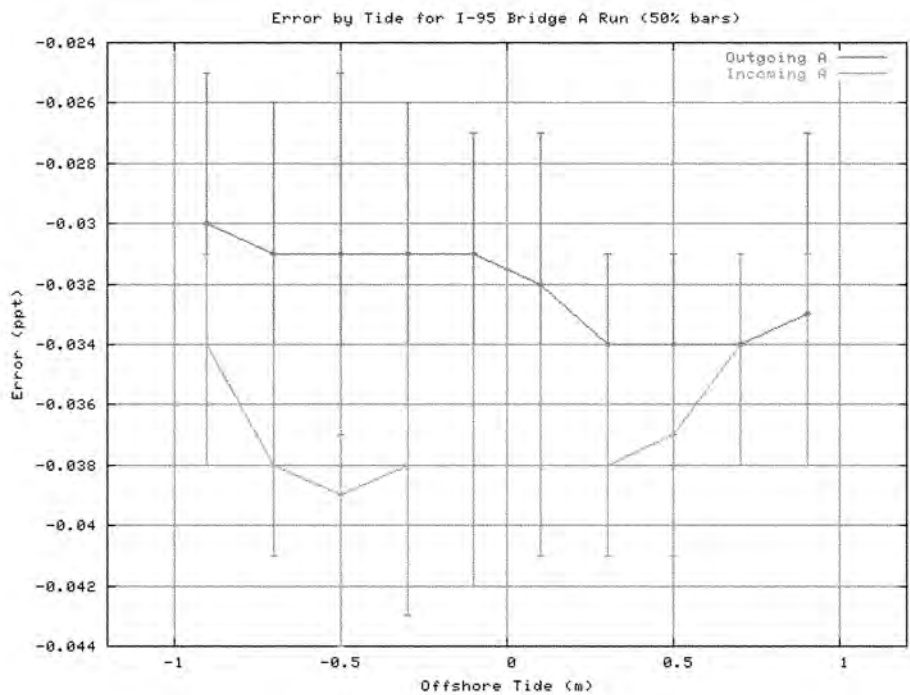


Figure 14.4: Error by tide, I-95 Bridge, 97-99

## 14.2 Performance on 2000-2003 run

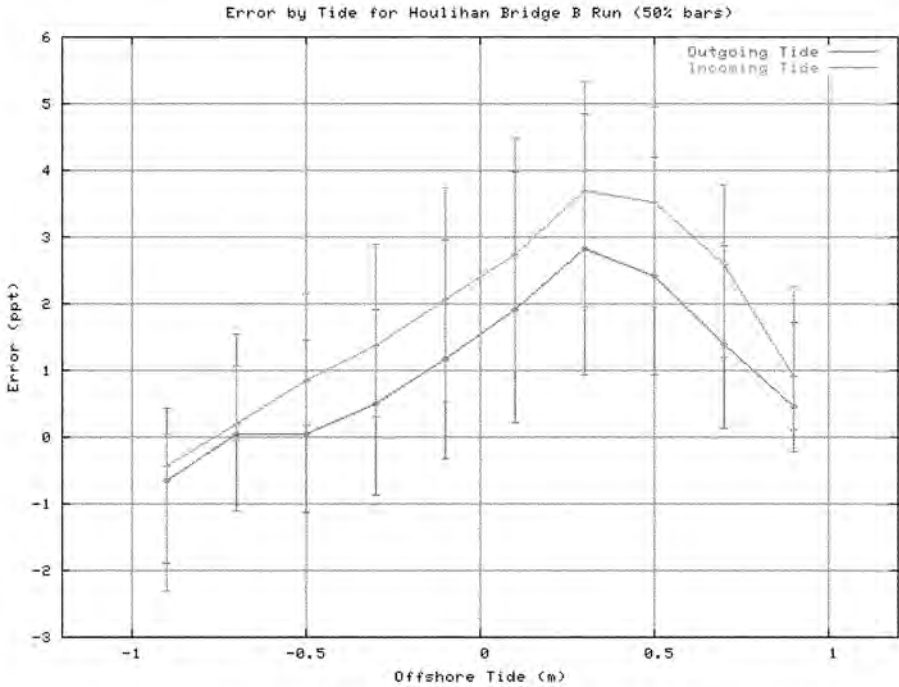


Figure 14.5: Error by tide, Houlihan Bridge, 00-03

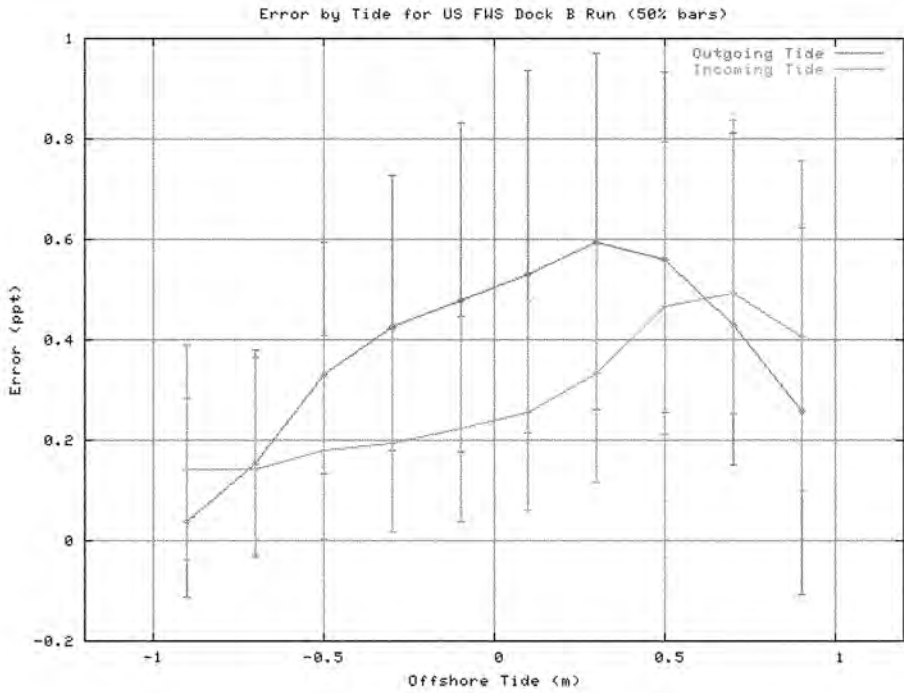


Figure 14.6: Error by tide, USFWS Dock, 00-03

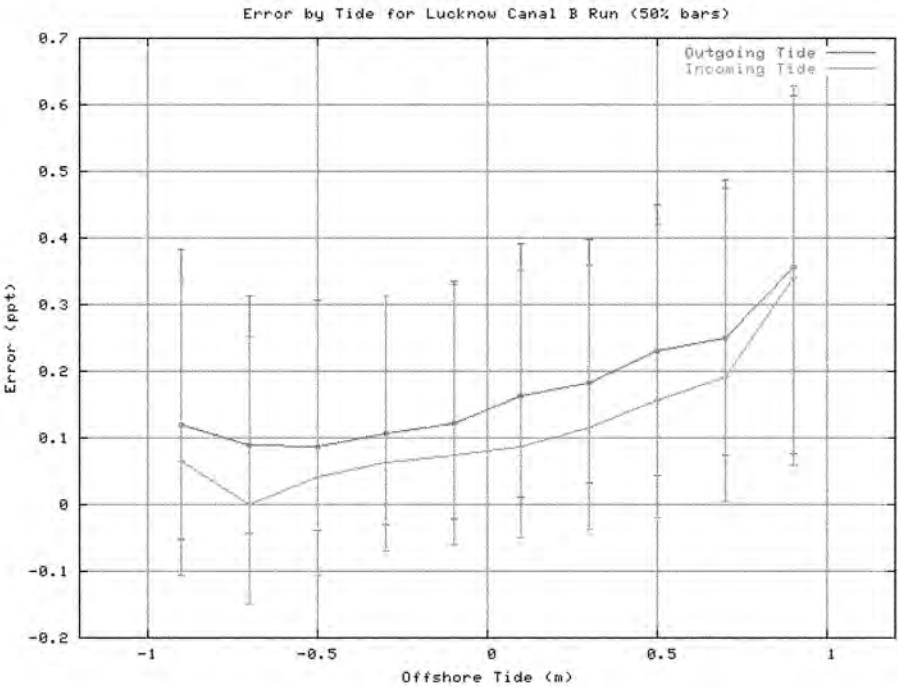


Figure 14.7: Error by tide, Lucknow Canal, 00-03

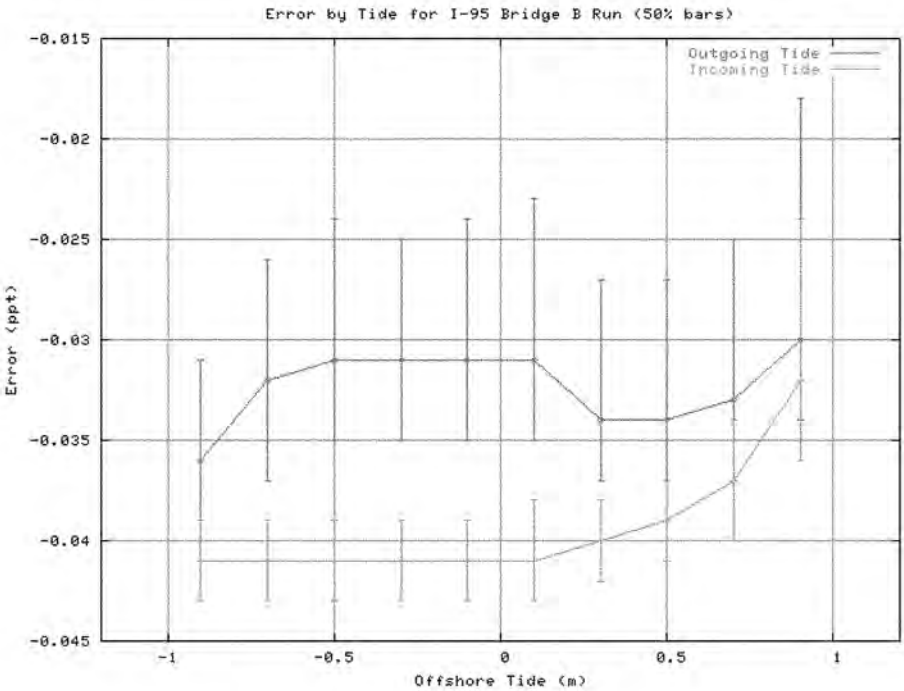


Figure 14.8: Error by tide, I-95 Bridge, 00-03





**APPENDIX T    1999 DISSOLVED OXYGEN: ATM CORRECTED  
DATA**



Table T-1 Summary Percentiles for Dissolved Oxygen (mg/l) for July 31, 1999 through October 13, 1999

| July 31 - October 13, 1999<br>[Julian Days 213-285] |       |               |            |               |               |            |               |               |            |               |
|-----------------------------------------------------|-------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                            | Depth | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                     |       | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                               | S     | 3.7           | 4.7        | 5.9           | 4.4           | 4.9        | 5.2           | 0.7           | 0.1        | -0.7          |
| FR-02                                               | B     | 3.3           | 3.7        | 4.4           | 4.0           | 4.2        | 4.4           | 0.7           | 0.5        | 0.0           |
| FR-04                                               | S     | 2.7           | 4.0        | 4.7           | 3.6           | 4.5        | 4.9           | 0.8           | 0.5        | 0.2           |
| FR-04                                               | B     | 2.9           | 3.6        | 4.2           | 3.2           | 4.1        | 4.4           | 0.3           | 0.5        | 0.1           |
| FR-06                                               | S     | 3.7           | 4.1        | 4.5           | 4.5           | 5.2        | 5.7           | 0.8           | 1.1        | 1.2           |
| FR-06                                               | B     | 2.3           | 3.3        | 3.8           | 3.0           | 3.7        | 4.0           | 0.7           | 0.4        | 0.2           |
| FR-08                                               | S     | 4.1           | 5.5        | 8.5           | 4.5           | 5.5        | 6.1           | 0.4           | 0.0        | -0.4          |
| FR-08                                               | B     | 2.2           | 3.9        | 5.7           | 3.3           | 4.4        | 5.6           | 1.1           | 0.5        | -0.2          |
| FR-09                                               | S     | 4.4           | 5.7        | 6.8           | 4.6           | 5.6        | 6.3           | 0.2           | -0.1       | -0.5          |
| FR-09                                               | B     | 2.9           | 4.7        | 6.2           | 3.9           | 4.7        | 5.7           | 1.0           | 0.0        | -0.5          |
| MR-10                                               | S     | 4.5           | 5.3        | 6.0           | 5.5           | 6.2        | 6.8           | 1.0           | 0.9        | 0.7           |
| FR-11R                                              | B     | 4.8           | 6.1        | 6.8           | 4.8           | 5.7        | 6.4           | 0.1           | -0.4       | -0.3          |
| SR-14                                               | B     | 6.1           | 6.5        | 7.2           | 5.9           | 6.3        | 6.8           | -0.3          | -0.2       | -0.4          |
| SR-16                                               | B     | 6.5           | 7.0        | 7.4           | 6.3           | 6.9        | 7.2           | -0.2          | -0.1       | -0.3          |
| FR-21                                               | S     | 3.2           | 4.4        | 4.9           | 3.9           | 4.9        | 5.4           | 0.7           | 0.5        | 0.6           |
| FR-21                                               | B     | 2.6           | 3.6        | 4.1           | 3.0           | 3.8        | 4.1           | 0.4           | 0.2        | 0.1           |
| FR-22                                               | S     | 4.2           | 5.2        | 6.0           | 4.5           | 5.5        | 6.0           | 0.2           | 0.3        | 0.0           |
| FR-22                                               | B     | 2.5           | 3.5        | 4.4           | 2.9           | 3.8        | 4.4           | 0.4           | 0.3        | 0.0           |

\* S = Surface  
B = Bottom

Table T-2 Summary Statistics for Dissolved Oxygen (mg/l) for July 31, 1999 through October 13, 1999

| July 31 - October 13, 1999<br>[Julian Days 213-285] |       |       |       |      |      |             |              |              |               |      |
|-----------------------------------------------------|-------|-------|-------|------|------|-------------|--------------|--------------|---------------|------|
| Station                                             | Depth | N     | ME    | AME  | RMS  | Mean<br>Obs | StDev<br>Obs | Mean<br>Pred | StDev<br>Pred | R^2  |
| FR-02                                               | S     | 6096  | 0.01  | 0.65 | 0.81 | 4.80        | 0.89         | 4.81         | 0.39          | 0.17 |
| FR-02                                               | B     | 737   | 0.43  | 0.45 | 0.51 | 3.76        | 0.37         | 4.19         | 0.16          | 0.60 |
| FR-04                                               | S     | 10271 | 0.44  | 0.66 | 0.83 | 3.87        | 0.82         | 4.32         | 0.54          | 0.27 |
| FR-04                                               | B     | 6791  | 0.33  | 0.36 | 0.49 | 3.58        | 0.51         | 3.91         | 0.47          | 0.53 |
| FR-06                                               | S     | 10837 | 1.01  | 1.01 | 1.08 | 4.11        | 0.32         | 5.12         | 0.44          | 0.26 |
| FR-06                                               | B     | 14947 | 0.42  | 0.47 | 0.56 | 3.15        | 0.60         | 3.57         | 0.38          | 0.65 |
| FR-08                                               | S     | 7682  | 0.04  | 0.55 | 0.68 | 5.35        | 0.89         | 5.39         | 0.59          | 0.41 |
| FR-08                                               | B     | 13700 | 0.51  | 0.86 | 1.10 | 3.91        | 1.33         | 4.42         | 0.81          | 0.47 |
| FR-09                                               | S     | 16350 | -0.07 | 0.59 | 0.74 | 5.59        | 0.86         | 5.52         | 0.61          | 0.30 |
| FR-09                                               | B     | 15124 | 0.11  | 0.61 | 0.79 | 4.63        | 1.24         | 4.74         | 0.72          | 0.65 |
| MR-10                                               | S     | 15388 | 0.87  | 0.95 | 1.06 | 5.28        | 0.63         | 6.15         | 0.52          | 0.20 |
| FR-11R                                              | B     | 13163 | -0.23 | 0.46 | 0.60 | 5.90        | 0.78         | 5.68         | 0.61          | 0.50 |
| SR-14                                               | B     | 12346 | -0.23 | 0.30 | 0.39 | 6.57        | 0.38         | 6.34         | 0.39          | 0.46 |
| FR-21                                               | S     | 16030 | 0.58  | 0.63 | 0.75 | 4.18        | 0.66         | 4.76         | 0.58          | 0.50 |
| FR-21                                               | B     | 7741  | 0.20  | 0.32 | 0.41 | 3.43        | 0.58         | 3.63         | 0.46          | 0.63 |
| FR-22                                               | S     | 18839 | 0.21  | 0.45 | 0.56 | 5.16        | 0.70         | 5.36         | 0.55          | 0.47 |
| FR-22                                               | B     | 12765 | 0.24  | 0.46 | 0.59 | 3.47        | 0.71         | 3.71         | 0.54          | 0.42 |

\* S = Surface  
B = Bottom

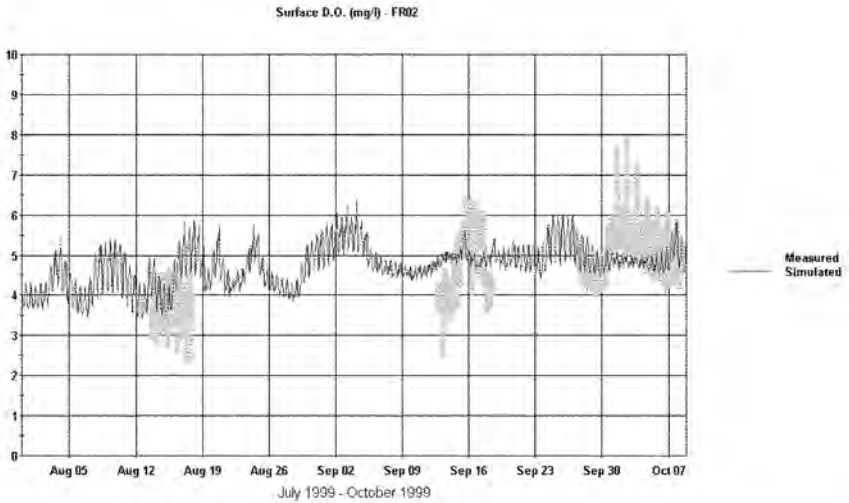


Figure T-1 Dissolved Oxygen Calibration at FR-02 (Surface) for July 31 through October 13, 1999

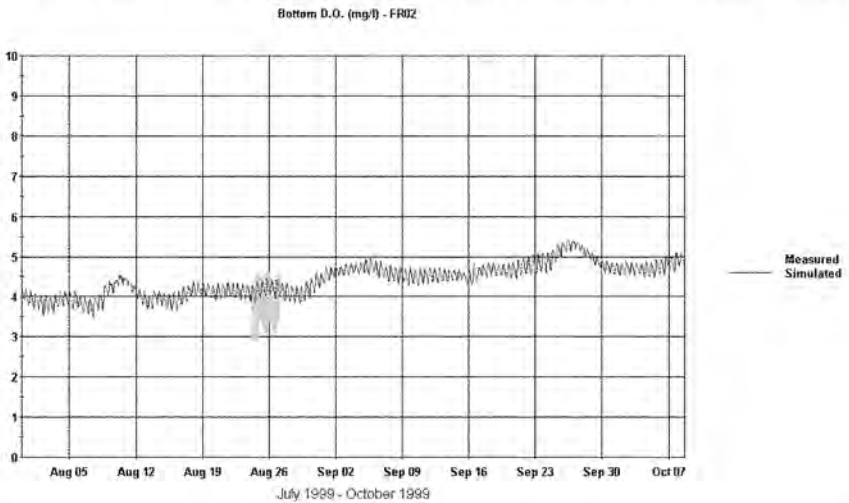


Figure T-2 Dissolved Oxygen Calibration at FR-02 (Bottom) for July 31 through October 13, 1999

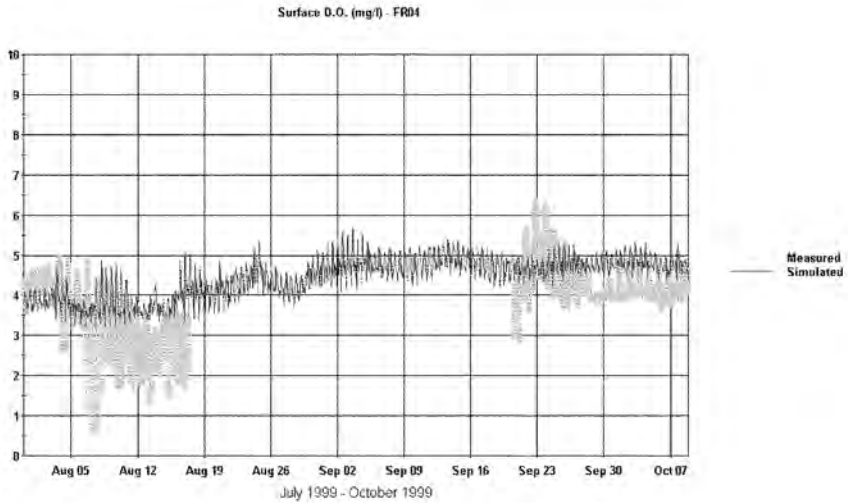


Figure T-3 Dissolved Oxygen Calibration at FR-04 (Surface) for July 31 through October 13, 1999

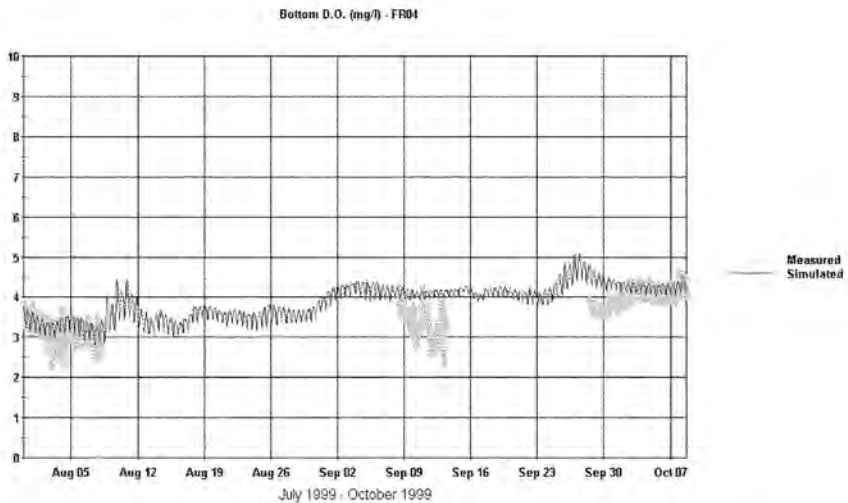


Figure T-4 Dissolved Oxygen Calibration at FR-04 (Bottom) for July 31 through October 13, 1999

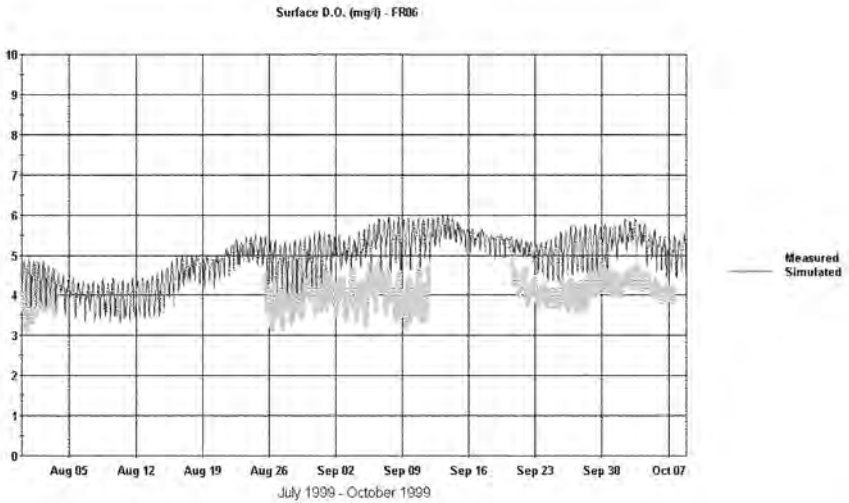


Figure T-5 Dissolved Oxygen Calibration at FR-06 (Surface) for July 31 through October 13, 1999

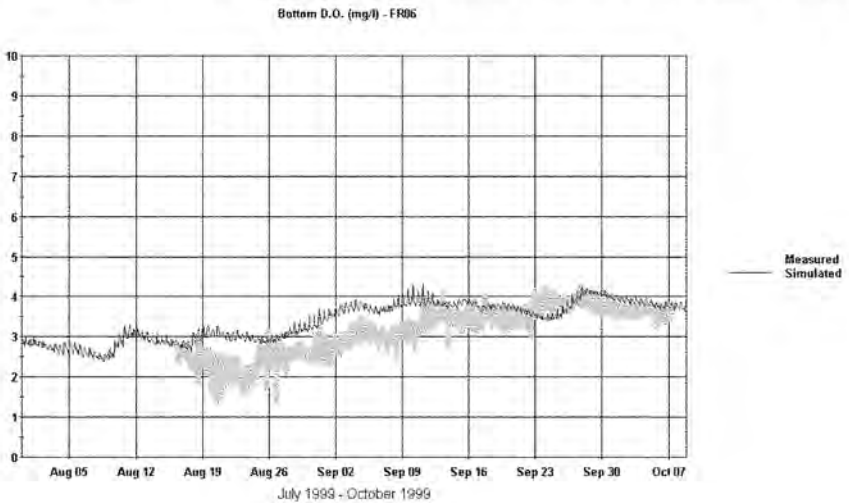


Figure T-6 Dissolved Oxygen Calibration at FR-06 (Bottom) for July 31 through October 13, 1999

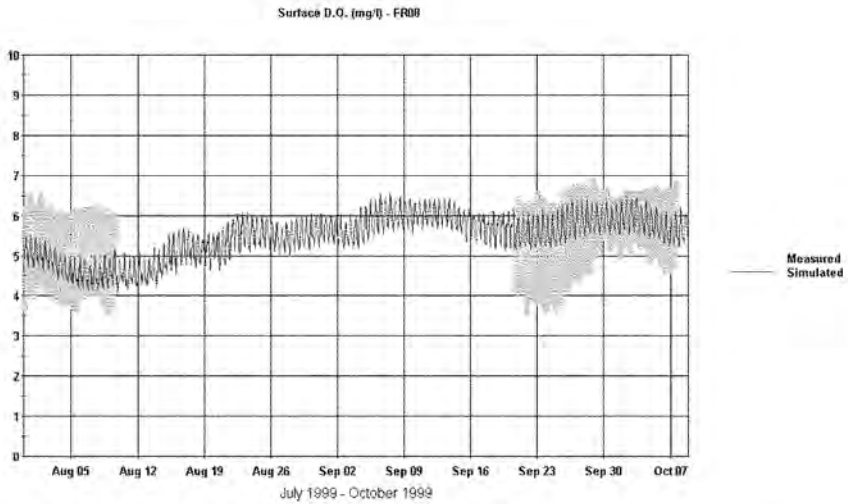


Figure T-7 Dissolved Oxygen Calibration at FR-08 (Surface) for July 31 through October 13, 1999

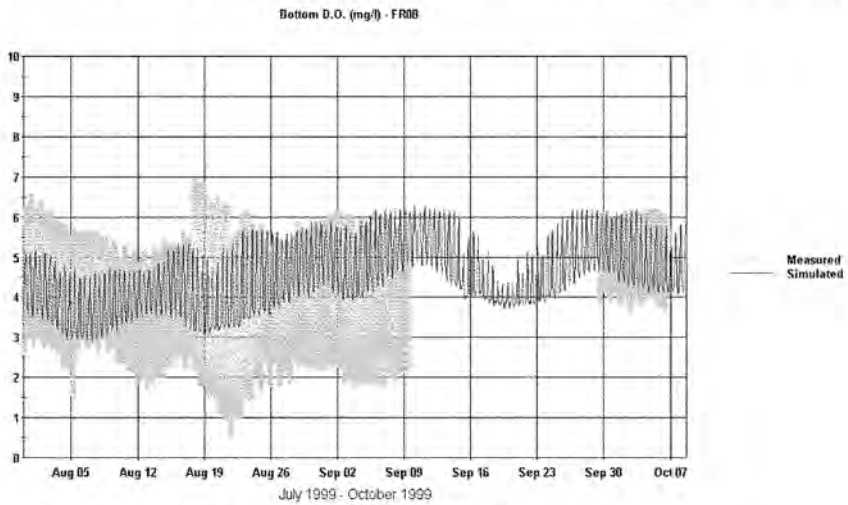


Figure T-8 Dissolved Oxygen Calibration at FR-08 (Bottom) for July 31 through October 13, 1999

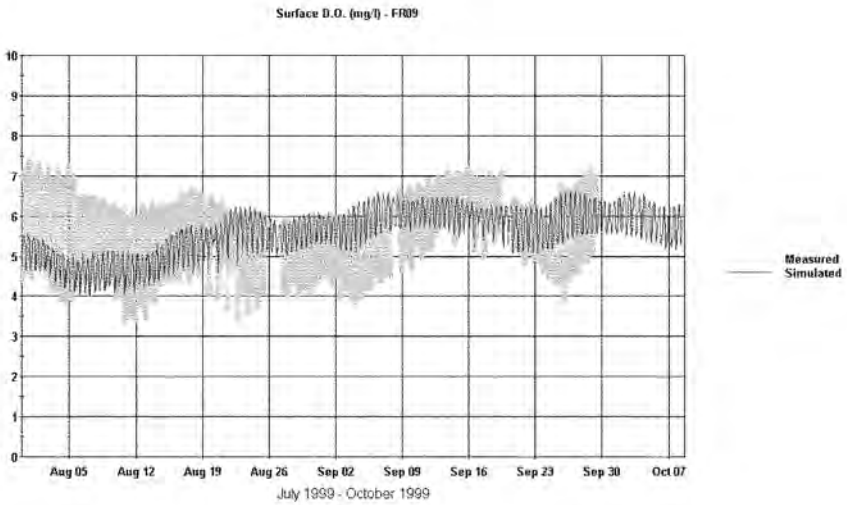


Figure T-9 Dissolved Oxygen Calibration at FR-09 (Surface) for July 31 through October 13, 1999

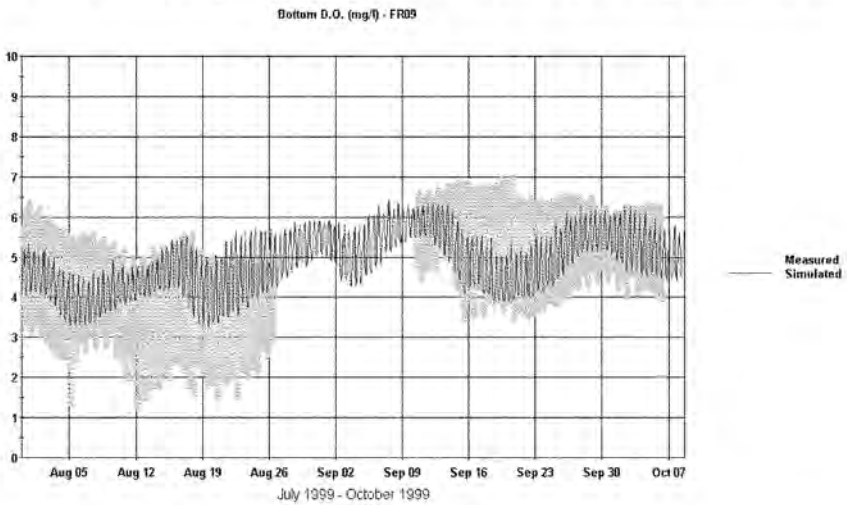


Figure T-10 Dissolved Oxygen Calibration at FR-09 (Bottom) for July 31 through October 13, 1999



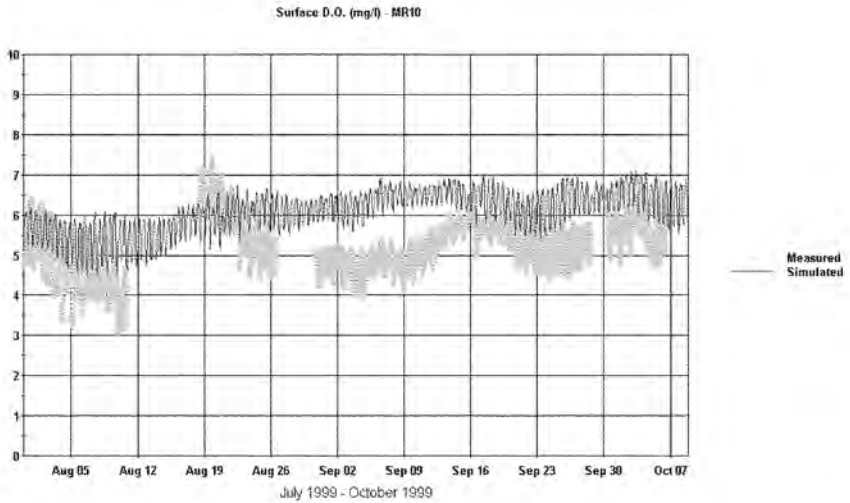


Figure T-11 Dissolved Oxygen Calibration at MR-10 (Surface) for July 31 through October 13, 1999

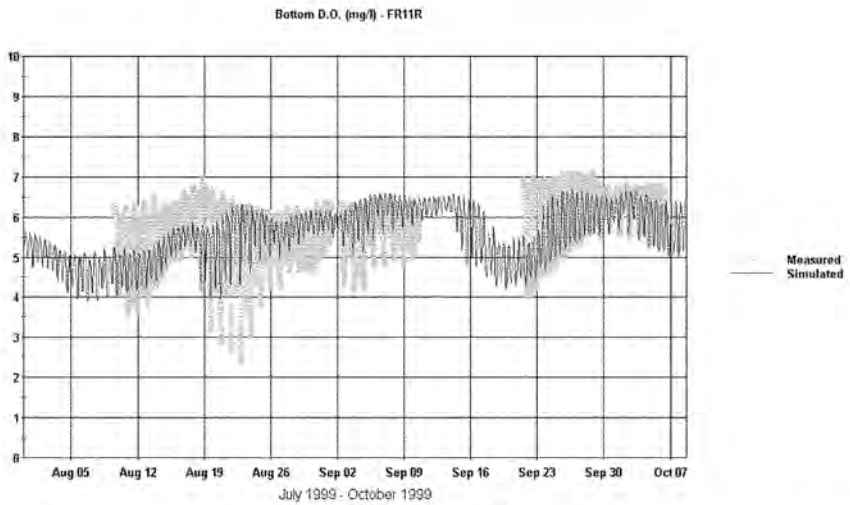


Figure T-12 Dissolved Oxygen Calibration at FR-11R (Bottom) for July 31 through October 13, 1999

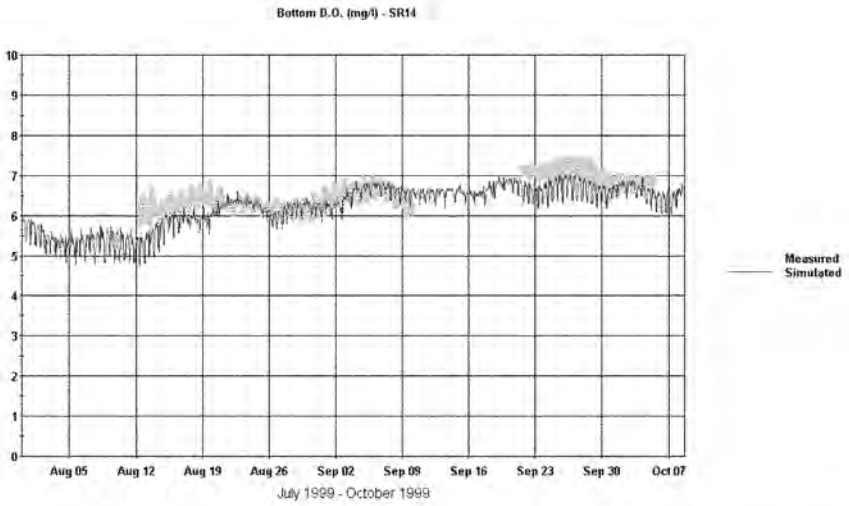


Figure T-13 Dissolved Oxygen Calibration at SR-14 (Bottom) for July 31 through October 13, 1999

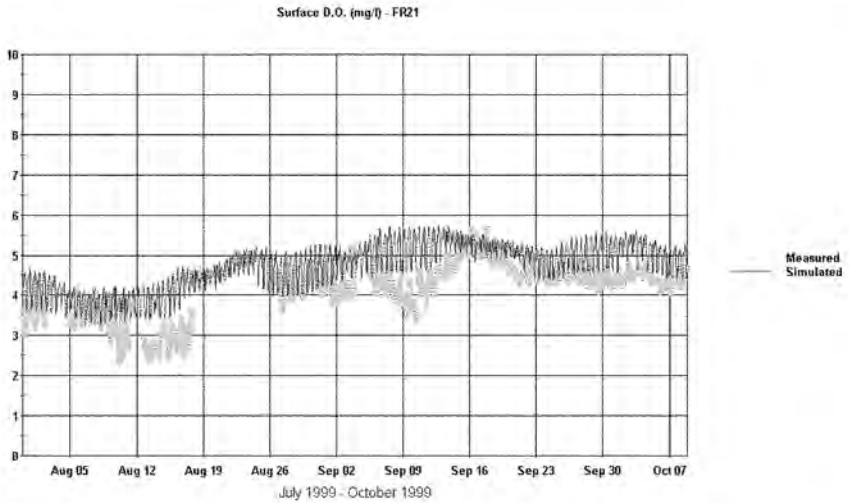


Figure T-14 Dissolved Oxygen Calibration at FR-21 (Surface) for July 31 through October 13, 1999

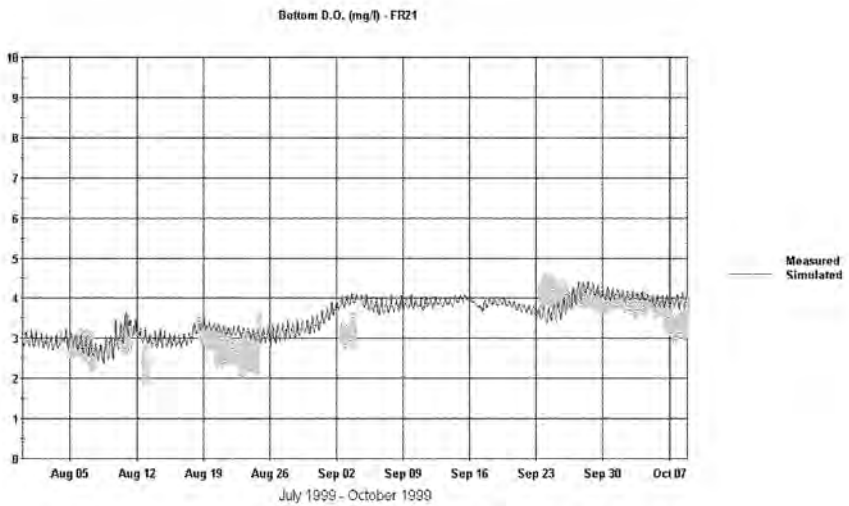


Figure T-15 Dissolved Oxygen Calibration at FR-21 (Bottom) for July 31 through October 13, 1999

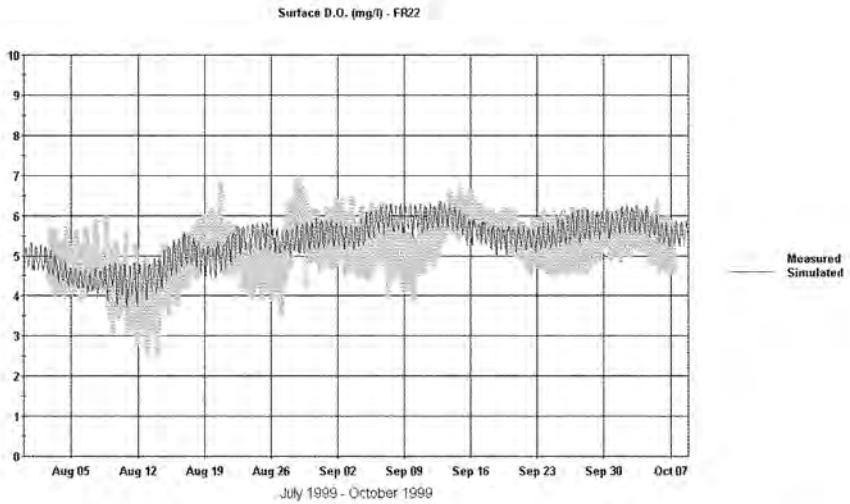


Figure T-16 Dissolved Oxygen Calibration at FR-22 (Surface) for July 31 through October 13, 1999

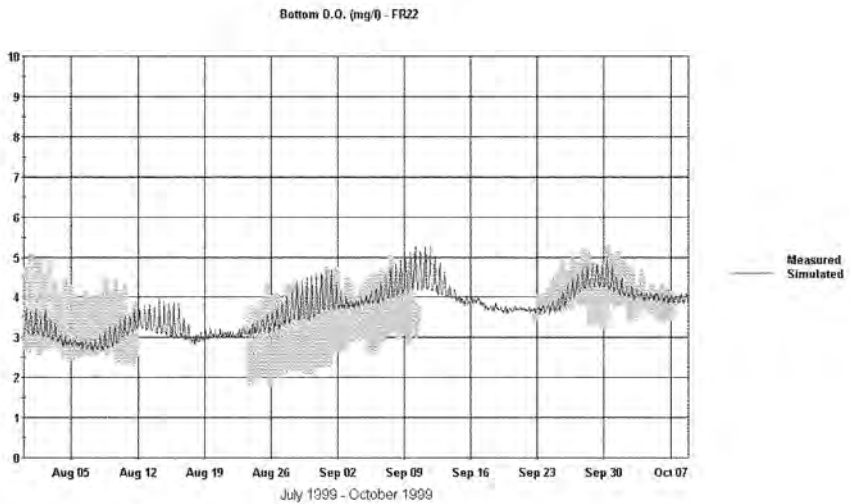


Figure T-17 Dissolved Oxygen Calibration at FR-22 (Bottom) for July 31 through October 13, 1999

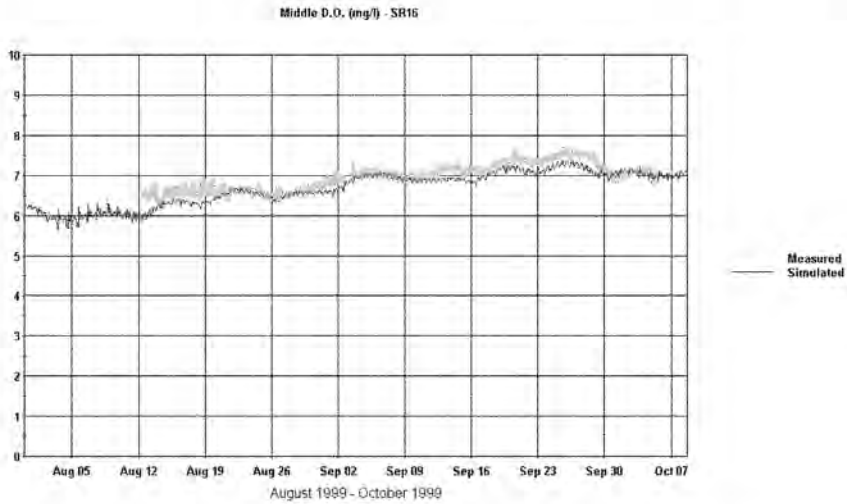


Figure T-18 Dissolved Oxygen Calibration at SR-16 (Mid-Depth) for July 31 through October 13, 1999

Table T-3 Summary Percentiles for Dissolved Oxygen (mg/l) for July 31, 1999 through August 15, 1999

| July 31 - August 15, 1999<br>[Julian Days 213-226] |        |               |            |               |               |            |               |               |            |               |
|----------------------------------------------------|--------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                           | Depth* | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                    |        | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                              | S      | 3.1           | 3.6        | 4.3           | 3.6           | 4.1        | 4.7           | 0.5           | 0.5        | 0.4           |
| FR-02                                              | B      |               |            |               |               |            |               |               |            |               |
| FR-04                                              | S      | 2.4           | 3.5        | 4.4           | 3.5           | 3.7        | 4.2           | 1.1           | 0.2        | -0.2          |
| FR-04                                              | B      | 2.8           | 3.2        | 3.5           | 3.1           | 3.3        | 3.5           | 0.3           | 0.2        | 0.0           |
| FR-06                                              | S      | 3.6           | 4.0        | 4.4           | 3.9           | 4.4        | 4.8           | 0.2           | 0.5        | 0.4           |
| FR-06                                              | B      |               |            |               |               |            |               |               |            |               |
| FR-08                                              | S      | 4.0           | 4.9        | 6.1           | 4.3           | 4.7        | 5.2           | 0.3           | -0.2       | -1.0          |
| FR-08                                              | B      | 2.7           | 3.7        | 5.5           | 3.1           | 3.9        | 4.7           | 0.4           | 0.1        | -0.8          |
| FR-09                                              | S      | 4.2           | 5.4        | 6.9           | 4.3           | 4.8        | 5.2           | 0.0           | -0.6       | -1.6          |
| FR-09                                              | B      | 2.8           | 4.1        | 5.5           | 3.6           | 4.2        | 4.8           | 0.8           | 0.1        | -0.6          |
| MR-10                                              | S      | 4.0           | 4.9        | 5.7           | 4.8           | 5.6        | 6.0           | 0.8           | 0.7        | 0.3           |
| FR-11R                                             | B      | 4.1           | 5.7        | 6.2           | 4.3           | 4.9        | 5.2           | 0.1           | -0.8       | -1.0          |
| SR-14                                              | B      |               |            |               |               |            |               |               |            |               |
| SR-16                                              | B      |               |            |               |               |            |               |               |            |               |
| FR-21                                              | S      | 2.7           | 3.4        | 3.9           | 3.5           | 3.9        | 4.3           | 0.8           | 0.6        | 0.4           |
| FR-21                                              | B      | 2.5           | 2.9        | 3.2           | 2.6           | 2.9        | 3.3           | 0.2           | 0.0        | 0.1           |
| FR-22                                              | S      | 3.4           | 4.4        | 5.3           | 4.1           | 4.5        | 4.8           | 0.7           | 0.1        | -0.5          |
| FR-22                                              | B      | 2.6           | 3.0        | 4.0           | 2.8           | 3.0        | 3.4           | 0.2           | 0.0        | -0.6          |

\* S = Surface  
B = Bottom

Table T-4 Summary Statistics for Dissolved Oxygen (mg/l) for July 31, 1999 through August 15, 1999

| July 31 - August 15, 1999<br>[Julian Days 213-226] |       |      |       |      |      |          |           |           |            |                |
|----------------------------------------------------|-------|------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Station                                            | Depth | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-02                                              | S     | 398  | 0.45  | 0.51 | 0.59 | 3.68     | 0.47      | 4.13      | 0.41       | 0.41           |
| FR-02                                              | B     |      |       |      |      |          |           |           |            |                |
| FR-04                                              | S     | 4267 | 0.35  | 0.66 | 0.88 | 3.45     | 0.81      | 3.80      | 0.28       | 0.03           |
| FR-04                                              | B     | 2362 | 0.16  | 0.22 | 0.29 | 3.15     | 0.30      | 3.31      | 0.18       | 0.39           |
| FR-06                                              | S     | 1033 | 0.41  | 0.44 | 0.52 | 3.98     | 0.31      | 4.39      | 0.33       | 0.26           |
| FR-06                                              | B     |      |       |      |      |          |           |           |            |                |
| FR-08                                              | S     | 2785 | -0.31 | 0.64 | 0.75 | 5.04     | 0.87      | 4.73      | 0.32       | 0.51           |
| FR-08                                              | B     | 4220 | -0.04 | 0.57 | 0.71 | 3.97     | 1.10      | 3.92      | 0.58       | 0.67           |
| FR-09                                              | S     | 4286 | -0.70 | 0.83 | 1.01 | 5.46     | 0.98      | 4.76      | 0.36       | 0.65           |
| FR-09                                              | B     | 4234 | 0.12  | 0.64 | 0.80 | 4.09     | 1.08      | 4.21      | 0.45       | 0.57           |
| MR-10                                              | S     | 3101 | 0.61  | 0.66 | 0.79 | 4.85     | 0.69      | 5.46      | 0.45       | 0.46           |
| FR-11R                                             | B     | 1454 | -0.56 | 0.69 | 0.78 | 5.33     | 0.82      | 4.78      | 0.35       | 0.74           |
| SR-14                                              | B     |      |       |      |      |          |           |           |            |                |
| FR-21                                              | S     | 3215 | 0.58  | 0.64 | 0.77 | 3.34     | 0.47      | 3.92      | 0.31       | 0.04           |
| FR-21                                              | B     | 1128 | 0.10  | 0.21 | 0.31 | 2.85     | 0.29      | 2.94      | 0.24       | 0.17           |
| FR-22                                              | S     | 3525 | 0.09  | 0.48 | 0.60 | 4.38     | 0.69      | 4.47      | 0.28       | 0.25           |
| FR-22                                              | B     | 3402 | -0.14 | 0.36 | 0.50 | 3.17     | 0.56      | 3.03      | 0.24       | 0.27           |

\* S = Surface  
B = Bottom

Table T-5 Summary Percentiles for Dissolved Oxygen (mg/l) for August 15, 1999 through August 30, 1999

| August 16 - August 30, 1999<br>[Julian Days 227-241] |                    |               |            |               |               |            |               |               |               |
|------------------------------------------------------|--------------------|---------------|------------|---------------|---------------|------------|---------------|---------------|---------------|
| Stations                                             | Depth <sup>a</sup> | Measured      |            |               | Simulated     |            |               | Difference    |               |
|                                                      |                    | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 90%<br>(mg/L) |
| FR-02                                                | S                  | 3.0           | 4.0        | 4.5           | 3.6           | 4.6        | 5.4           | 0.6           | 0.8           |
| FR-02                                                | B                  | 3.3           | 3.7        | 4.4           | 4.0           | 4.2        | 4.4           | 0.7           | 0.0           |
| FR-04                                                | S                  |               |            |               |               |            |               |               |               |
| FR-04                                                | B                  |               |            |               |               |            |               |               |               |
| FR-06                                                | S                  | 3.5           | 3.9        | 4.4           | 4.3           | 4.9        | 5.3           | 0.8           | 0.9           |
| FR-06                                                | B                  | 1.9           | 2.4        | 2.7           | 2.8           | 3.0        | 3.2           | 0.9           | 0.5           |
| FR-08                                                | S                  |               |            |               |               |            |               |               |               |
| FR-08                                                | B                  | 1.6           | 3.2        | 5.4           | 3.3           | 4.1        | 5.4           | 1.7           | 0.0           |
| FR-09                                                | S                  | 4.3           | 5.6        | 6.3           | 4.9           | 5.5        | 6.0           | 0.6           | -0.3          |
| FR-09                                                | B                  | 2.1           | 4.1        | 4.9           | 3.6           | 4.6        | 5.4           | 1.5           | 0.5           |
| MR-10                                                | S                  | 5.0           | 5.9        | 6.7           | 5.6           | 6.1        | 6.6           | 0.6           | -0.2          |
| FR-11R                                               | B                  | 4.5           | 6.0        | 6.4           | 4.9           | 5.6        | 6.1           | 0.4           | -0.4          |
| SR-14                                                | B                  | 6.1           | 6.3        | 6.5           | 5.8           | 6.1        | 6.3           | -0.3          | -0.2          |
| SR-16                                                | B                  | 6.5           | 6.6        | 6.7           | 6.3           | 6.5        | 6.6           | -0.2          | -0.1          |
| FR-21                                                | S                  | 2.8           | 3.8        | 4.5           | 3.9           | 4.4        | 5.0           | 1.1           | 0.5           |
| FR-21                                                | B                  | 2.4           | 2.8        | 3.2           | 3.0           | 3.2        | 3.3           | 0.8           | 0.1           |
| FR-22                                                | S                  | 4.3           | 5.1        | 5.9           | 4.8           | 5.2        | 5.7           | 0.5           | -0.2          |
| FR-22                                                | B                  | 2.1           | 2.5        | 3.8           | 3.2           | 3.4        | 3.9           | 1.1           | 0.1           |

<sup>a</sup> S = Surface

B = Bottom

Table T-6 Summary Statistics for Dissolved Oxygen (mg/l) for August 15, 1999 through August 30, 1999

| August 16 - August 30, 1999<br>[Julian Days 227-241] |       |      |       |      |      |             |              |              |               |                |
|------------------------------------------------------|-------|------|-------|------|------|-------------|--------------|--------------|---------------|----------------|
| Station                                              | Depth | N    | ME    | AME  | RMS  | Mean<br>Obs | StDev<br>Obs | Mean<br>Pred | StDev<br>Pred | R <sup>2</sup> |
| FR-02                                                | S     | 872  | 0.69  | 0.81 | 1.00 | 3.87        | 0.55         | 4.56         | 0.60          | 0.04           |
| FR-02                                                | B     | 737  | 0.43  | 0.45 | 0.51 | 3.76        | 0.37         | 4.19         | 0.16          | 0.60           |
| FR-04                                                | S     |      |       |      |      |             |              |              |               |                |
| FR-04                                                | B     |      |       |      |      |             |              |              |               |                |
| FR-06                                                | S     | 1222 | 0.94  | 0.94 | 0.99 | 3.95        | 0.37         | 4.88         | 0.37          | 0.43           |
| FR-06                                                | B     | 3850 | 0.64  | 0.65 | 0.73 | 2.36        | 0.33         | 3.00         | 0.14          | 0.01           |
| FR-08                                                | S     |      |       |      |      |             |              |              |               |                |
| FR-08                                                | B     | 4233 | 0.76  | 1.03 | 1.22 | 3.46        | 1.50         | 4.22         | 0.77          | 0.70           |
| FR-09                                                | S     | 3741 | 0.08  | 0.51 | 0.64 | 5.42        | 0.74         | 5.50         | 0.39          | 0.26           |
| FR-09                                                | B     | 3420 | 0.80  | 0.87 | 1.04 | 3.75        | 1.09         | 4.55         | 0.64          | 0.69           |
| MR-10                                                | S     | 2300 | 0.20  | 0.66 | 0.76 | 5.85        | 0.65         | 6.05         | 0.35          | 0.00           |
| FR-11R                                               | B     | 4172 | -0.21 | 0.49 | 0.64 | 5.73        | 0.82         | 5.53         | 0.47          | 0.47           |
| SR-14                                                | B     | 4233 | -0.21 | 0.25 | 0.34 | 6.29        | 0.16         | 6.08         | 0.22          | 0.00           |
| FR-21                                                | S     | 1785 | 0.73  | 0.79 | 0.94 | 3.66        | 0.67         | 4.39         | 0.42          | 0.24           |
| FR-21                                                | B     | 1807 | 0.41  | 0.42 | 0.47 | 2.79        | 0.31         | 3.19         | 0.11          | 0.56           |
| FR-22                                                | S     | 4219 | 0.18  | 0.54 | 0.65 | 5.06        | 0.62         | 5.23         | 0.33          | 0.05           |
| FR-22                                                | B     | 1706 | 0.71  | 0.78 | 0.86 | 2.75        | 0.65         | 3.46         | 0.29          | 0.51           |

<sup>a</sup> S = Surface

B = Bottom

Table T-7 Summary Percentiles for Dissolved Oxygen (mg/l) for August 30, 1999 through September 13, 1999

| August 31 - September 13, 1999<br>[Julian Days 242 - 255] |                    |               |            |               |               |            |               |               |            |               |
|-----------------------------------------------------------|--------------------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                                  | Depth <sup>a</sup> | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                           |                    | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                                     | S                  |               |            |               |               |            |               |               |            |               |
| FR-02                                                     | B                  |               |            |               |               |            |               |               |            |               |
| FR-04                                                     | S                  |               |            |               |               |            |               |               |            |               |
| FR-04                                                     | B                  | 2.9           | 3.4        | 4.0           | 4.0           | 4.1        | 4.2           | 1.1           | 0.7        | 0.2           |
| FR-06                                                     | S                  | 3.6           | 4.1        | 4.5           | 4.6           | 5.3        | 5.8           | 1.1           | 1.2        | 1.3           |
| FR-06                                                     | B                  | 2.6           | 3.0        | 3.5           | 3.4           | 3.7        | 3.9           | 0.7           | 0.7        | 0.4           |
| FR-08                                                     | S                  |               |            |               |               |            |               |               |            |               |
| FR-08                                                     | B                  | 2.3           | 3.5        | 5.6           | 4.1           | 5.0        | 5.8           | 1.9           | 1.4        | 0.2           |
| FR-09                                                     | S                  | 4.4           | 5.7        | 6.6           | 5.4           | 5.9        | 6.4           | 1.0           | 0.2        | -0.2          |
| FR-09                                                     | B                  | 4.9           | 6.0        | 6.6           | 5.4           | 5.8        | 6.2           | 0.5           | -0.1       | -0.3          |
| MR-10                                                     | S                  | 4.5           | 4.9        | 5.4           | 5.9           | 6.4        | 6.7           | 1.5           | 1.5        | 1.3           |
| FR-11R                                                    | B                  | 5.0           | 6.1        | 6.3           | 5.6           | 6.1        | 6.5           | 0.6           | 0.0        | 0.1           |
| SR-14                                                     | B                  | 6.2           | 6.5        | 6.8           | 6.2           | 6.5        | 6.8           | 0.0           | 0.0        | 0.0           |
| SR-16                                                     | B                  | 6.8           | 7.0        | 7.1           | 6.6           | 6.9        | 7.0           | -0.2          | -0.1       | -0.1          |
| FR-21                                                     | S                  | 3.9           | 4.3        | 4.7           | 4.5           | 5.0        | 5.6           | 0.7           | 0.8        | 0.9           |
| FR-21                                                     | B                  | 2.6           | 3.1        | 3.5           | 3.8           | 3.9        | 4.0           | 1.0           | 0.8        | 0.6           |
| FR-22                                                     | S                  | 4.7           | 5.4        | 6.1           | 5.3           | 5.8        | 6.2           | 0.7           | 0.3        | 0.1           |
| FR-22                                                     | B                  | 2.6           | 3.4        | 4.3           | 3.7           | 4.0        | 4.6           | 1.1           | 0.6        | 0.2           |

<sup>a</sup> S = Surface  
B = Bottom

Table T-8 Summary Statistics for Dissolved Oxygen (mg/l) for August 30, 1999 through September 13, 1999

| August 31 - September 13, 1999<br>[Julian Days 242 - 255] |       |      |       |      |      |             |              |              |               |                |
|-----------------------------------------------------------|-------|------|-------|------|------|-------------|--------------|--------------|---------------|----------------|
| Station                                                   | Depth | N    | ME    | AME  | RMS  | Mean<br>Obs | StDev<br>Obs | Mean<br>Pred | StDev<br>Pred | R <sup>2</sup> |
| FR-02                                                     | S     |      |       |      |      |             |              |              |               |                |
| FR-02                                                     | B     |      |       |      |      |             |              |              |               |                |
| FR-04                                                     | S     |      |       |      |      |             |              |              |               |                |
| FR-04                                                     | B     | 1369 | 0.68  | 0.68 | 0.78 | 3.41        | 0.41         | 4.09         | 0.08          | 0.17           |
| FR-06                                                     | S     | 3726 | 1.20  | 1.20 | 1.26 | 4.06        | 0.33         | 5.26         | 0.37          | 0.18           |
| FR-06                                                     | B     | 4276 | 0.64  | 0.65 | 0.68 | 3.05        | 0.32         | 3.70         | 0.21          | 0.56           |
| FR-08                                                     | S     |      |       |      |      |             |              |              |               |                |
| FR-08                                                     | B     | 3211 | 1.21  | 1.33 | 1.55 | 3.78        | 1.24         | 4.99         | 0.64          | 0.39           |
| FR-09                                                     | S     | 4080 | 0.41  | 0.53 | 0.65 | 5.52        | 0.78         | 5.93         | 0.36          | 0.74           |
| FR-09                                                     | B     | 777  | 0.01  | 0.34 | 0.43 | 5.82        | 0.61         | 5.83         | 0.31          | 0.55           |
| MR-10                                                     | S     | 3969 | 1.46  | 1.46 | 1.49 | 4.92        | 0.36         | 6.38         | 0.28          | 0.27           |
| FR-11R                                                    | B     | 3221 | 0.19  | 0.31 | 0.42 | 5.86        | 0.54         | 6.05         | 0.33          | 0.54           |
| SR-14                                                     | B     | 3405 | -0.01 | 0.18 | 0.22 | 6.48        | 0.23         | 6.47         | 0.24          | 0.30           |
| FR-21                                                     | S     | 3781 | 0.77  | 0.81 | 0.92 | 4.27        | 0.32         | 5.04         | 0.41          | 0.01           |
| FR-21                                                     | B     | 401  | 0.79  | 0.79 | 0.82 | 3.13        | 0.24         | 3.92         | 0.09          | 0.22           |
| FR-22                                                     | S     | 4255 | 0.39  | 0.50 | 0.62 | 5.38        | 0.54         | 5.76         | 0.30          | 0.20           |
| FR-22                                                     | B     | 3424 | 0.61  | 0.65 | 0.75 | 3.44        | 0.64         | 4.05         | 0.34          | 0.58           |

<sup>a</sup> S = Surface  
B = Bottom



Table T-9 Summary Percentiles for Dissolved Oxygen (mg/l) for September 13, 1999 through September 28, 1999

| September 14 - September 28, 1999<br>[Julian Days 256 - 270] |        |               |            |               |               |            |               |               |            |               |
|--------------------------------------------------------------|--------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                                     | Depth* | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                              |        | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                                        | S      | 41            | 49         | 59            | 47            | 49         | 53            | 0.7           | 0.1        | -0.6          |
| FR-02                                                        | B      |               |            |               |               |            |               |               |            |               |
| FR-04                                                        | S      | 40            | 45         | 55            | 45            | 47         | 50            | 0.6           | 0.2        | -0.5          |
| FR-04                                                        | B      |               |            |               |               |            |               |               |            |               |
| FR-06                                                        | S      | 3.8           | 41         | 44            | 4.6           | 5.2        | 5.5           | 0.8           | 1.1        | 1.1           |
| FR-06                                                        | B      | 3.3           | 3.6        | 40            | 3.5           | 3.7        | 3.9           | 0.2           | 0.1        | 0.0           |
| FR-08                                                        | S      | 4.0           | 5.0        | 6.4           | 5.3           | 5.6        | 6.2           | 1.3           | 0.6        | -0.3          |
| FR-08                                                        | B      |               |            |               |               |            |               |               |            |               |
| FR-09                                                        | S      | 4.7           | 6.0        | 6.9           | 5.3           | 6.0        | 6.4           | 0.6           | -0.1       | -0.6          |
| FR-09                                                        | B      | 3.8           | 5.3        | 6.6           | 4.0           | 4.9        | 5.7           | 0.3           | -0.4       | -0.9          |
| MR-10                                                        | S      | 4.8           | 5.5        | 5.9           | 5.8           | 6.4        | 6.8           | 1.0           | 0.8        | 0.9           |
| FR-11R                                                       | B      | 4.7           | 6.5        | 7.0           | 4.7           | 6.4        | 6.6           | -0.1          | -1.1       | -0.5          |
| SR-14                                                        | B      | 7.0           | 7.2        | 7.4           | 6.3           | 6.7        | 6.9           | -0.6          | -0.5       | -0.4          |
| SR-16                                                        | B      | 7.1           | 7.3        | 7.6           | 6.9           | 7.1        | 7.3           | -0.2          | -0.2       | -0.3          |
| FR-21                                                        | S      | 4.4           | 4.7        | 5.2           | 4.6           | 5.1        | 5.4           | 0.3           | 0.4        | 0.2           |
| FR-21                                                        | B      | 3.9           | 4.0        | 4.4           | 3.5           | 3.8        | 4.2           | -0.4          | -0.3       | -0.2          |
| FR-22                                                        | S      | 4.8           | 5.6        | 6.1           | 5.3           | 5.6        | 6.0           | 0.5           | 0.0        | -0.2          |
| FR-22                                                        | B      | 3.7           | 4.0        | 4.6           | 3.7           | 3.8        | 4.3           | 0.0           | -0.1       | -0.3          |

\* S = Surface  
B = Bottom

Table T-10 Summary Statistics for Dissolved Oxygen (mg/l) for September 13, 1999 through September 28, 1999

| September 14 - September 28, 1999<br>[Julian Days 256 - 270] |       |      |       |      |      |          |            |           |             |      |
|--------------------------------------------------------------|-------|------|-------|------|------|----------|------------|-----------|-------------|------|
| Station                                                      | Depth | N    | ME    | AME  | RMS  | Mean Obs | StdDev Obs | Mean Pred | StdDev Pred | R^2  |
| FR-02                                                        | S     | 1706 | 0.03  | 0.66 | 0.75 | 4.94     | 0.73       | 4.98      | 0.22        | 0.01 |
| FR-02                                                        | B     |      |       |      |      |          |            |           |             |      |
| FR-04                                                        | S     | 2333 | 0.14  | 0.54 | 0.69 | 4.62     | 0.62       | 4.75      | 0.18        | 0.02 |
| FR-04                                                        | B     |      |       |      |      |          |            |           |             |      |
| FR-06                                                        | S     | 2284 | 1.02  | 1.02 | 1.06 | 4.08     | 0.23       | 5.11      | 0.32        | 0.20 |
| FR-06                                                        | B     | 4286 | 0.09  | 0.26 | 0.31 | 3.64     | 0.25       | 3.73      | 0.17        | 0.00 |
| FR-08                                                        | S     | 2289 | 0.52  | 0.71 | 0.85 | 5.15     | 0.93       | 5.67      | 0.32        | 0.77 |
| FR-08                                                        | B     |      |       |      |      |          |            |           |             |      |
| FR-09                                                        | S     | 3984 | -0.02 | 0.45 | 0.54 | 5.92     | 0.79       | 5.90      | 0.37        | 0.64 |
| FR-09                                                        | B     | 4233 | -0.37 | 0.62 | 0.78 | 5.21     | 1.08       | 4.85      | 0.62        | 0.66 |
| MR-10                                                        | S     | 4252 | 0.87  | 0.87 | 0.94 | 5.46     | 0.40       | 6.34      | 0.38        | 0.40 |
| FR-11R                                                       | B     | 1815 | -0.58 | 0.62 | 0.80 | 6.12     | 0.90       | 5.54      | 0.67        | 0.63 |
| SR-14                                                        | B     | 1838 | -0.50 | 0.50 | 0.53 | 7.17     | 0.16       | 6.67      | 0.23        | 0.34 |
| FR-21                                                        | S     | 4278 | 0.33  | 0.40 | 0.47 | 4.77     | 0.33       | 5.10      | 0.28        | 0.16 |
| FR-21                                                        | B     | 1267 | -0.28 | 0.34 | 0.42 | 4.07     | 0.19       | 3.79      | 0.26        | 0.01 |
| FR-22                                                        | S     | 4276 | 0.07  | 0.32 | 0.39 | 5.52     | 0.50       | 5.60      | 0.26        | 0.43 |
| FR-22                                                        | B     | 1478 | -0.14 | 0.19 | 0.24 | 4.05     | 0.35       | 3.92      | 0.26        | 0.71 |

\* S = Surface  
B = Bottom

Table T-11 Summary Percentiles for Dissolved Oxygen (mg/l) for September 28, 1999 through October 13, 1999

| September 29 - October 13, 1999<br>(Julian Days 271-285) |        |               |            |               |               |            |               |               |            |               |
|----------------------------------------------------------|--------|---------------|------------|---------------|---------------|------------|---------------|---------------|------------|---------------|
| Stations                                                 | Depth* | Measured      |            |               | Simulated     |            |               | Difference    |            |               |
|                                                          |        | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) | 10%<br>(mg/L) | 50% (mg/L) | 90%<br>(mg/L) |
| FR-02                                                    | S      | 4.3           | 5.2        | 6.1           | 4.5           | 4.8        | 5.1           | 0.3           | -0.3       | -1.0          |
| FR-02                                                    | B      |               |            |               |               |            |               |               |            |               |
| FR-04                                                    | S      | 3.9           | 4.1        | 4.5           | 4.6           | 4.8        | 5.1           | 0.7           | 0.7        | 0.6           |
| FR-04                                                    | B      | 3.7           | 4.0        | 4.4           | 4.1           | 4.3        | 4.5           | 0.4           | 0.3        | 0.1           |
| FR-06                                                    | S      | 4.1           | 4.3        | 4.6           | 4.8           | 5.4        | 5.7           | 0.8           | 1.0        | 1.1           |
| FR-06                                                    | B      | 3.5           | 3.7        | 3.8           | 3.8           | 3.9        | 4.1           | 0.2           | 0.3        | 0.3           |
| FR-08                                                    | S      | 5.0           | 5.9        | 6.6           | 5.5           | 5.8        | 6.2           | 0.5           | 0.0        | -0.4          |
| FR-08                                                    | B      | 4.0           | 4.8        | 6.0           | 4.3           | 4.9        | 5.9           | 0.3           | 0.1        | -0.1          |
| FR-09                                                    | S      | 5.2           | 6.7        | 7.1           | 5.6           | 6.1        | 6.4           | 0.4           | -0.6       | -0.7          |
| FR-09                                                    | B      | 4.4           | 5.6        | 6.1           | 4.7           | 5.4        | 6.0           | 0.3           | -0.1       | -0.1          |
| MR-10                                                    | S      | 5.1           | 5.6        | 6.2           | 6.0           | 6.6        | 7.0           | 0.9           | 1.0        | 0.8           |
| FR-11R                                                   | B      | 5.7           | 6.6        | 6.6           | 5.5           | 6.2        | 6.5           | -0.2          | -0.4       | -0.3          |
| SR-14                                                    | B      | 6.6           | 6.9        | 7.2           | 6.3           | 6.7        | 6.8           | -0.3          | -0.2       | -0.3          |
| SR-16                                                    | B      | 6.9           | 7.1        | 7.5           | 7.0           | 7.1        | 7.1           | 0.0           | -0.1       | -0.3          |
| FR-21                                                    | S      | 4.3           | 4.5        | 4.7           | 4.6           | 5.1        | 5.4           | 0.3           | 0.6        | 0.7           |
| FR-21                                                    | B      | 3.5           | 3.8        | 4.0           | 3.8           | 4.0        | 4.2           | 0.4           | 0.2        | 0.2           |
| FR-22                                                    | S      | 4.9           | 5.4        | 6.0           | 5.5           | 5.8        | 6.1           | 0.6           | 0.3        | 0.2           |
| FR-22                                                    | B      | 3.5           | 3.9        | 4.7           | 4.0           | 4.1        | 4.5           | 0.5           | 0.2        | -0.1          |

\* S = Surface  
B = Bottom

Table T-12 Summary Statistics for Dissolved Oxygen (mg/l) for September 28, 1999 through October 13, 1999

| September 29 - October 13, 1999<br>(Julian Days 271-285) |       |      |       |      |      |          |           |           |            |                |
|----------------------------------------------------------|-------|------|-------|------|------|----------|-----------|-----------|------------|----------------|
| Station                                                  | Depth | N    | ME    | AME  | RMS  | Mean Obs | StDev Obs | Mean Pred | StDev Pred | R <sup>2</sup> |
| FR-02                                                    | S     | 2867 | -0.36 | 0.58 | 0.78 | 5.23     | 0.72      | 4.87      | 0.22       | 0.09           |
| FR-02                                                    | B     |      |       |      |      |          |           |           |            |                |
| FR-04                                                    | S     | 3096 | 0.68  | 0.68 | 0.75 | 4.12     | 0.23      | 4.80      | 0.18       | 0.02           |
| FR-04                                                    | B     | 3144 | 0.27  | 0.30 | 0.40 | 4.04     | 0.27      | 4.31      | 0.14       | 0.00           |
| FR-06                                                    | S     | 2574 | 1.00  | 1.00 | 1.03 | 4.33     | 0.22      | 5.33      | 0.31       | 0.48           |
| FR-06                                                    | B     | 2538 | 0.25  | 0.25 | 0.28 | 3.67     | 0.13      | 3.92      | 0.12       | 0.27           |
| FR-08                                                    | S     | 2609 | -0.01 | 0.33 | 0.38 | 5.86     | 0.60      | 5.85      | 0.28       | 0.77           |
| FR-08                                                    | B     | 2036 | 0.05  | 0.35 | 0.45 | 4.95     | 0.83      | 5.00      | 0.62       | 0.72           |
| FR-09                                                    | S     | 263  | -0.33 | 0.55 | 0.60 | 6.38     | 0.72      | 6.05      | 0.33       | 0.63           |
| FR-09                                                    | B     | 2460 | 0.01  | 0.27 | 0.33 | 5.38     | 0.67      | 5.39      | 0.46       | 0.79           |
| MR-10                                                    | S     | 1768 | 0.88  | 0.88 | 0.95 | 5.65     | 0.39      | 6.53      | 0.36       | 0.33           |
| FR-11R                                                   | B     | 2501 | -0.34 | 0.36 | 0.42 | 6.42     | 0.43      | 6.08      | 0.41       | 0.70           |
| SR-14                                                    | B     | 2222 | -0.24 | 0.27 | 0.32 | 6.87     | 0.21      | 6.63      | 0.18       | 0.13           |
| FR-21                                                    | S     | 4260 | 0.55  | 0.56 | 0.64 | 4.50     | 0.19      | 5.05      | 0.32       | 0.06           |
| FR-21                                                    | B     | 3338 | 0.24  | 0.25 | 0.30 | 3.79     | 0.23      | 4.02      | 0.14       | 0.34           |
| FR-22                                                    | S     | 2568 | 0.34  | 0.35 | 0.40 | 5.43     | 0.39      | 5.77      | 0.24       | 0.77           |
| FR-22                                                    | B     | 2755 | 0.17  | 0.30 | 0.37 | 4.02     | 0.43      | 4.19      | 0.24       | 0.45           |

\* S = Surface  
B = Bottom

## **APPENDIX U    INDEPENDENT TECHNICAL REVIEW (ITR) COMMENTS AND RESPONSES**



Responses revised on November 9, 2005 based on October 26, 2005 Review meeting.

Review Subject: Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project

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EFDC and WASP7 were chosen to model hydrodynamics and water quality of the Savannah River. Two models are linked through an interface. Model grid coverage appears adequate. Grid resolution also appears appropriate (Figures 4-1 through 4-7).

## 1. COMMENT

### ***Basis of Concern (law/policy):***

Convergence test (Appendix A)

### ***Significance of Concern:***

Second sentence on A-4 states "slightly greater stratification" at Houlihan Bridge. Figure A-3 only shows surface salinity. It seems the differences between two grids diverge with time. If this is true, then it indicates failure in convergence test. Also nothing is quantified.

### ***Specific Actions Needed to Resolve:***

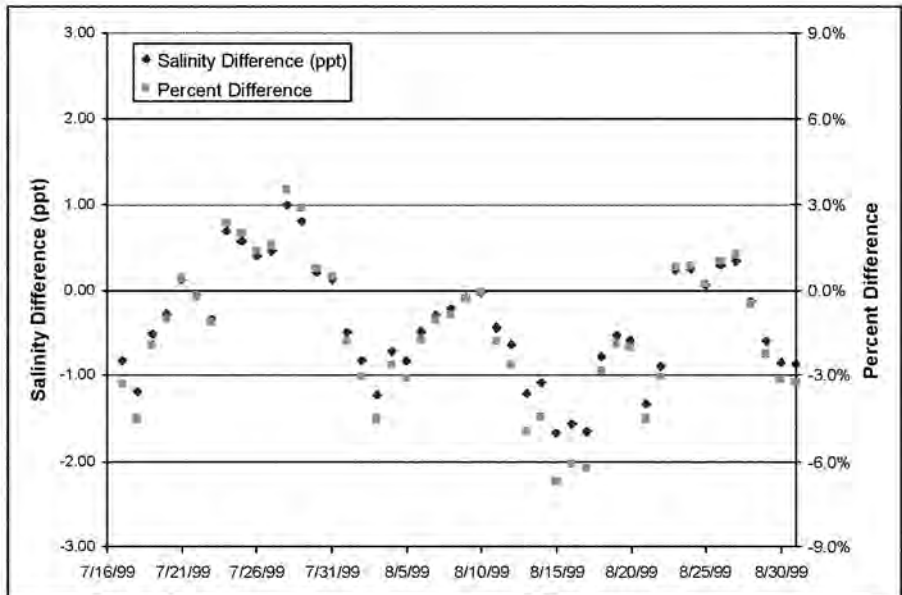
Add bottom salinity time series. It may be helpful to show the time series plots for differences to demonstrate there is no divergence. Need to devise a way to quantify the convergence.

### ***Response and review action by author:***

Figure A-2 shows bottom salinity at Houlihan Bridge, while Figure A-3 shows the surface salinity for comparison of Enhanced Grid and Convergence Grid results. The "slightly greater stratification" phrase should be modified to indicate that slightly less salinity (difference is more apparent at surface) is observed in the Convergence Grid results. The final modeling report will be updated and revised with this discussion. Quantification of the convergence grid test results has been performed and is presented in the following tables. Model spin up (15 days) has been excluded from these statistics.

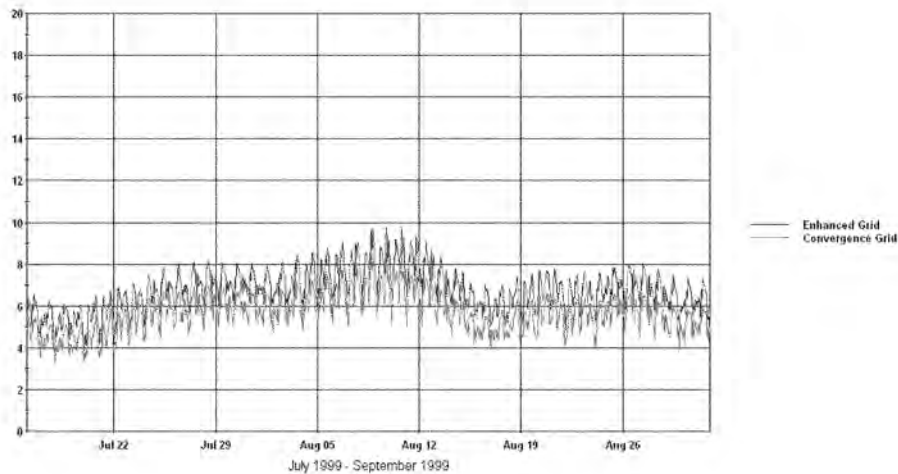
| Site  | Layer   | Enhanced Grid<br>Average<br>Salinity (ppt) | Convergence<br>Grid Average<br>Salinity (ppt) | Average<br>Difference<br>(ppt) | Average<br>Percent<br>Difference |
|-------|---------|--------------------------------------------|-----------------------------------------------|--------------------------------|----------------------------------|
| FR-09 | Bottom  | 27.27                                      | 26.83                                         | -0.43                          | -1.6%                            |
| FR-09 | Surface | 6.78                                       | 5.69                                          | -1.09                          | -16.2%                           |
| SR-17 | Bottom  | 0.005                                      | 0.006                                         | 0.001                          | 21.9%                            |

A plot of the daily average salinity difference and percent difference at FR-09 Bottom shows no consistent trend of difference (no divergence with time). The minor difference in system response for each grid may depend more on hydrologic or tidal conditions.

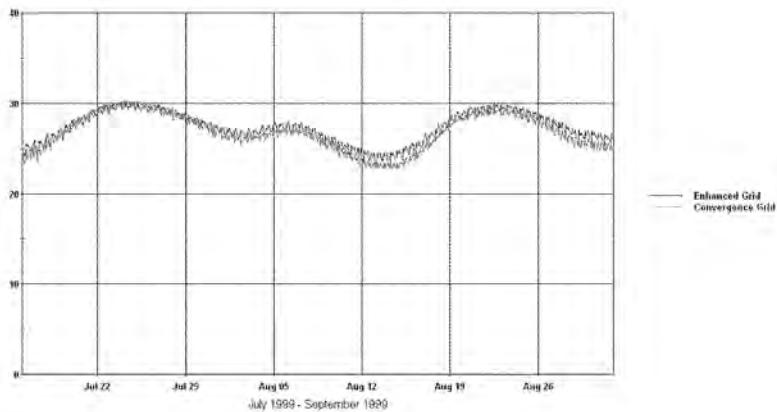


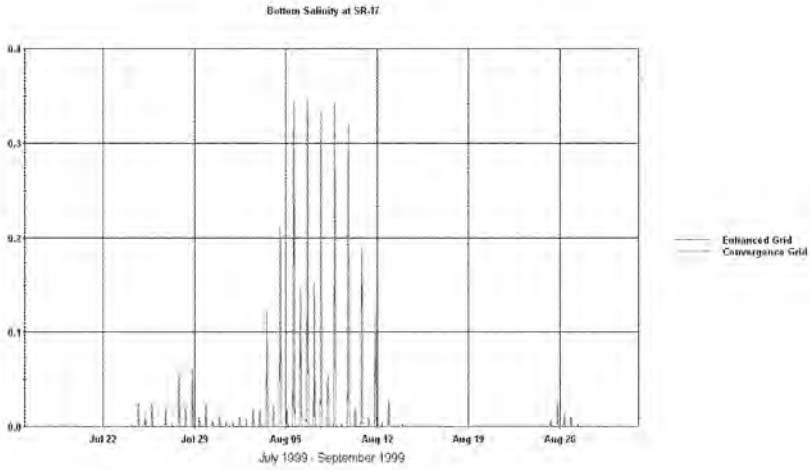
Here are the revised figures that will be included in the final report:

Surface Salinity at Houlihan Bridge (FR09)



Bottom Salinity at Houlihan Bridge (FR09)



**Response by reviewer:**

I concur. Comment closed.



## 2. COMMENT

### ***Basis of Concern (law/policy):***

Bottom roughness is set as 0.02 m.

### ***Significance of Concern:***

This indicates a physical roughness length of .6 m that is a big number.

### ***Specific Actions Needed to Resolve:***

It will be good to add more explanation for the nature of the roughness. It will be also good to put the values for the other estuaries for comparison.

### ***Response and review action by author:***

From developer Dr. John Hamrick in an email on May 30, 2005: "The value of 0.02 roughness is more reasonable. The 0.02 was used for all VIMS EFDC applications in the James River where the model did very well in predicting a lot of different things including salinity, current meter transects at James River Bridge, and frontal structure at Newport News Point. Conversely, the James model used an approximately 400 m grid and I think much of the  $Z_o$  may be sub-grid scale topography. For the Savannah model, the attribution to lateral effects may have some bearing since the lateral resolution may not capture resistance of very shallow areas. Another possibility is the effect of moored ships and port structures. I have been working in Portland Oregon Harbor (Lower Willamette River) and we have played with adding various sub scale features such as piers and moored ships using the vegetation resistance. (Vegetation resistance is quite general in that it can represent any type of sub-grid scale obstacle in the flow view in terms of a projected obstruction area normal to flow per unit horizontal area. For example, piers or piles would be  $N \cdot D \cdot H / dx \cdot dy$ ,  $N$  = number of pilings per cell,  $D$  diameter,  $H$  water depth or fraction of water depth,  $dx \cdot dy$  horizontal area). Adding such features greatly improved model predications for currents observations from zig-zag ADCP profiles in river. As to the sensitivity, there would not be much change between 0.015, 0.02, and 0.025. A value of 0.01 may be more appropriate for sensitivity. Of course, if we ultimately model sediment transport, the more important thing is the ability to separate the grain scale bed stress from the total bed stress. This has been done fairly successfully in the EFDC application to the Housatonic River PCB superfund site and is also being used in the above Portland Harbor application, which is also a contaminated sediment superfund site."

In a previous email from Dr. John Hamrick on May 27, 2005 with Dr. Kim: "I agree that the  $Z_o$  of 0.03 m is rather large. I have typically used  $Z_o$  ranging from 0.0005 to 0.02 for estuary applications. My rationale for the larger values is that, in addition to representing the actual bed grain scale roughness, the  $Z_o$  accounts for larger scale effects which could include bed form drag, drag due to obstacles in flow, and drag implied by sub-grid scale topographic variability. The  $Z_o$  is basically calibrated to achieve correct amplitude attenuation and phase propagate for the tide. With this in mind, other features such as unaccounted marsh storage, etc. could influence the choice of  $Z_o$  globally to achieve the calibration to the tide. Of course, in an estuary where there is little apparent propagation and the tide has more of a standing wave characteristic,

the tidal calibration can be relatively insensitive to  $Z_0$ . In this case, larger values of  $Z_0$  would tend to be used to increase vertical mixing if necessary to calibrate to stratification and length of salinity intrusion. In a strongly stratified estuary, such as Savannah, the turbulence model can tend to over stratify since phenomena such as internal wave breaking, which would enhance mixing, are not represented. I suggest that Steven and his group do some sensitivity, at least reducing  $Z_0$  to 0.01. Looking ahead to sediment transport, EFDC includes a procedure to estimate the so called grain stress by partitioning the total stress into grain and form components. Typically, the grain component responsible for sediment resuspension can end up being from 5 to 50 percent of the total stress. I can provide some details on this if you are interested."

***Response by reviewer:***

I concur. Comment closed.

### 3. COMMENT

***Basis of Concern (law/policy):***

Salinity error was set to be within 10 % for salt water

***Significance of Concern:***

The criteria was difficult to meet. There is not enough explanation regarding the salinity simulation shown in Appendix J. It is difficult to see whether the federal expectation criteria was met. If not, there need to be an explanation.

***Specific Actions Needed to Resolve:***

Need more explanation and discussion of salinity distribution.

***Response and review action by author:***

The federal expectations document states that the proposed preliminary criteria should be viewed as performance goals to which model predictions could be compared and evaluated. The criteria alone should not be used for a pass/fail evaluation of the model calibration.

The criteria were established for the stations: GPA 5, 6, 7, 8, 9, 10, 11R, 12R, 15, and 22 and five USGS stations. The July 31-October 13 (Appendix J) calibration results show that the model met the criteria for USGS stations 80% (4/5) and for GPA stations 21% (3/14) for 10<sup>th</sup> percentile and 29% (4/14) for 90<sup>th</sup> percentile. Correlation of simulations and observations was meaningful (>0.6) for 80% of USGS stations and 79% (11/14) of GPA stations. The difference in meeting criteria for USGS and GPA sites can be explained partly by quality and duration of compared data. The average duration of data for USGS stations is 100% of the simulated period of time, and only 50-70% for GPA stations due to data gaps. This explains some problematic aspects of comparing percentiles of simulation results with incomplete data.

We agree that more detailed discussion of the salinity calibration is useful and this will be included in the revised final report.

***Response by reviewer:***

I concur. Comment closed.

#### 4. COMMENT

***Basis of Concern (law/policy):***

Sediment oxygen demand

***Significance of Concern:***

The sediment diagenesis model of WASP7 was not activated. Instead SOD was set as a function of temperature and location in the system. Source of SOD would be carbons deposited during winter time. The limit of using this model should be clearly stated because full sediment diagenesis is not modeled. There may be yearly variation for summer SOD depending on the flow conditions of previous years.

***Specific Actions Needed to Resolve:***

State the limit of this model. Also state recommendation of having more SOD monitoring.

***Response and review action by author:***

We agree with the comment that a sediment diagenesis model may improve SOD representation within the WASP model. However, this version of WASP with sediment diagenesis is not available. The current version of WASP (WASP7) can only input SOD as a function of space and temperature, rather than simulating SOD with sediment diagenesis calculations. The current approach is based on using available observed data that are generalized by functions of spatial distribution and temperature. We agree that SOD effects dominate the dissolved oxygen results for the estuary and we support the idea of future SOD monitoring by cooperating agencies in the SHE project. Even though SOD data were collected in 1999 by EPA, additional SOD monitoring can be useful in areas such as the Back, Little Back, and Middle Rivers.

***Response by reviewer:***

I concur. Comment closed.

## **APPENDIX V    SHE MODEL REVIEW TEAM COMMENTS AND RESPONSES**



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**REVISED TECHNICAL MEMORANDUM NO. 3**

**Date:** October 25, 2005, Revised on November 14, 2005  
**To:** Agency Technical Review Group  
**From:** Steven Davie  
**Cc:** Joe Hoke, Alan Garrett, and Bill Bailey - USACE Savannah District  
**Subject:** Response to Agency Comments on the Savannah Harbor Models  
Tt Project No. 16807-01

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Tetra Tech, Inc. (Tetra Tech) has been developing the EFDC and WASP models for the Savannah Harbor Estuary. During this effort, Tetra Tech has developed two prior memorandums to communicate with the Agency Technical Review Group. Technical Memorandum No. 1 was distributed on December 10, 2004 dealing with the model grid enhancements. Technical Memorandum No. 2 was distributed on March 16, 2005 that entailed an update on the EFDC and WASP calibrations. This memo (No. 3) is a response to the agency comments outlined in the meeting on June 16, 2005 in Atlanta, Georgia.

During the June 16, 2005 meeting, the federal and state agencies made comments on the Final Modeling report dated May 20, 2005. The purpose of this meeting and discussion was to have an additional round of comments to address any concerns dealing with the model calibration. Agency letters were submitted to the USACE Savannah District that approved moving forward with the model while addressing the group's comments satisfactorily. The group had a wide-ranging discussion at the June meeting and the comments were categorized into 12 topics. The paragraph on the next page was the group's attempt to develop categories for the comments that describe the amount of effort expected to address a concern. The following discussion presents each of the 12 comments and Tetra Tech's response. These comments and responses were discussed at the October 26, 2005 meeting in Atlanta, Georgia. These issues will be considered further before using the models to identify impacts of the recommended plan.

**Ways to address concerns with the models and the reports**

The group categorized the concerns according to the level of action that is appropriate to fully address each concern. The following four categories were developed, roughly in order of the effort expected:

- A** Explain better in the report, no modeling action needed.
- B** Keep in mind when interpreting the model results.
- C** Additional sensitivity model runs are needed.
- D** Recalibrate / revise model.

(note: a "C" action could turn into a "D" action depending on the results)

**Summary of concerns and actions to address each concern [option from above]:****COMMENT 1: [B] Marsh water quality loads:**

- a. **[A]** Inclusion in the enhanced grid
- b. **[A]** Equal comparison between the TMDL and enhanced grids
- c. **[C]** Is the CBODu too high?
- d. **[C]** Mass exchange – flows and concentration
- e. **[C]** Surface to bottom – CBODu vertical differences are a function of how marsh areas were loaded into the enhanced model

**RESPONSE 1:**

- a. The enhanced grid contains 16 marsh cells: 3 along Front River, 4 along Middle River, and 9 along Back River. TMDL model grid had 9 marsh cells along Middle and Back River. Areas of TMDL model marshes were set in accordance with ATM Q-zones assessments. Marsh areas of enhanced grid model were based on the same Q-zone areas and adjusted during calibration process for capturing flows and salinity trends in upper part of estuary.
- b. Total marsh CBODu loads for enhanced grid water quality model were set up equal to total marsh CBODu loads of the USEPA TMDL model (Greenfield, 2004). The last ones were quantified based on field measurements. The 9 TMDL model marsh loads were redistributed between 16 enhanced model marsh loads in accordance with their locations and areas.
- c. The surface layer values of CBODu were too high in the calibration report. At that time, we were adding the loads from the marsh areas to the surface layer only. After our modification described in (e) below, the surface layer values are much lower and closer to the data.
- d. Similar to the response (e), we feel that after the adjustment to the marsh loads, the mass exchange is more appropriate in the top three layers and the model results are closer correlated to the data.
- e. Initial approach presented in Tetra Tech Report (May, 2005) was to input marsh CBODu loads in the surface layer (Figure 1). During the June meeting, there was a concern about high CBODu model results compared to the data and the stratification of CBODu in these areas. To address the concern Tetra Tech found it was appropriate to redistribute the loads between top three layers. The results of revised approach are shown in Figure 2 as an example on the Middle River (MR-12R). The load redistribution does not show any noticeable effect on CBODu and dissolved oxygen dynamics on the Front River.

**RESPONSE 1 SUMMARY:** Tetra Tech revised the WASP model by spreading the marsh loads into the top three layers instead of the surface layer only.



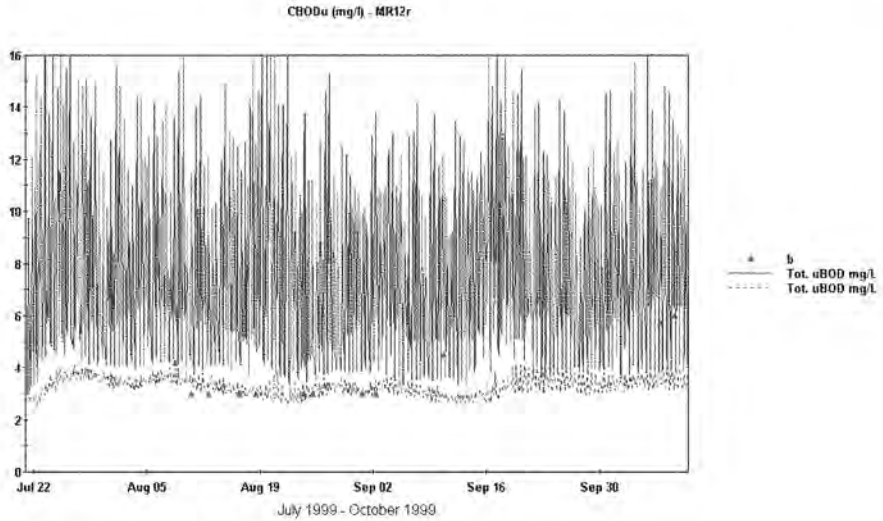


Figure 1 - Loads in the Surface Layer as Presented in the May 20, 2005 Report

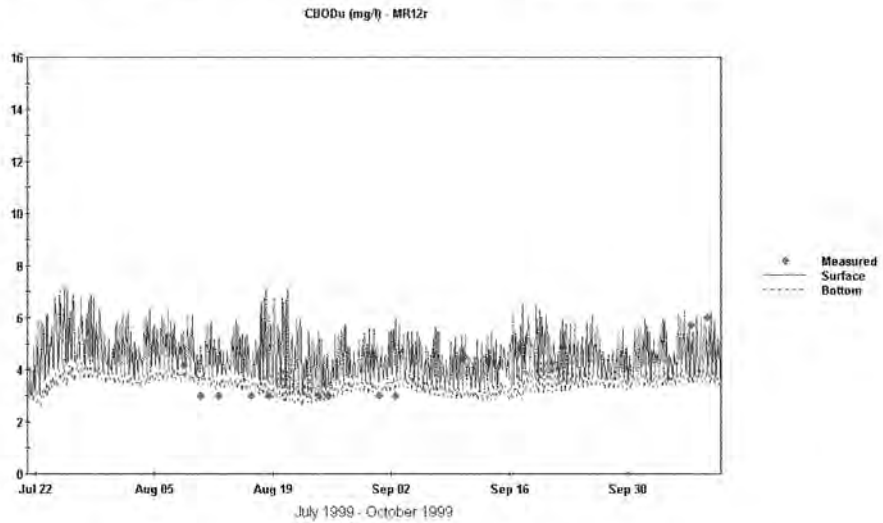


Figure 2 – Revised Approach with the Loads in the Top Three Surface Layers

**COMMENT 2: [C] Offshore boundary:**

a. Salinity 34 to 36 ppt versus 32.5 to 35 ppt, Mass flux surface to bottom – may need to re-distribute at FR-26.

**RESPONSE 2a:** The calibration boundary was determined to be a best-fit linear function from 32.5 ppt (surface) to 35 ppt (bottom). The issue was raised that based on “World Ocean Atlas” annual means, that regional annual mean value of surface salinity may be in the range 34-36 ppt. For comparison, data from Sabsoon site R2 that is located approx. 50 miles offshore from the mouth of the Savannah River indicate mean surface salinity of 36.0 ppt (range 31.5-36.5 in the period 1999-2002), however, this site is much farther from the effects of littoral freshwater inflows than the model boundary 17 miles offshore from Oysterbed Island. To assess model sensitivity and the possibility of improving the calibration, the EFDC model was run for 35 ppt (surface to bottom) and 36 ppt constant boundary conditions. Results were increased salinity in the lower Front River both at the surface and the bottom. As expected, predicted salinity was increased more at Ft. Pulaski (FR-26) than upstream at sites such as FR-08, for example. Results are shown in Figures 3 through 6 for FR-26 and FR-08. We conclude that increasing the offshore boundary condition for salinity does not improve the calibration.

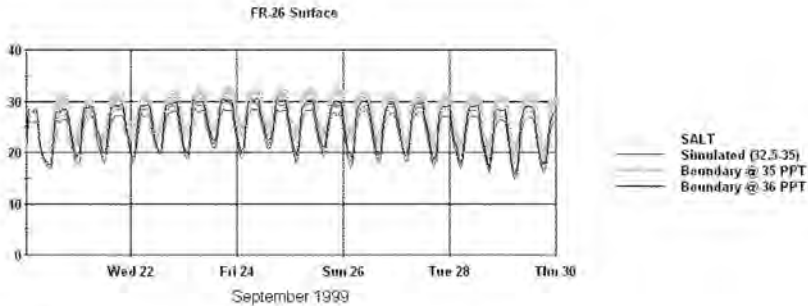


Figure 3 – Salinity Comparisons at FR-26 at the Surface

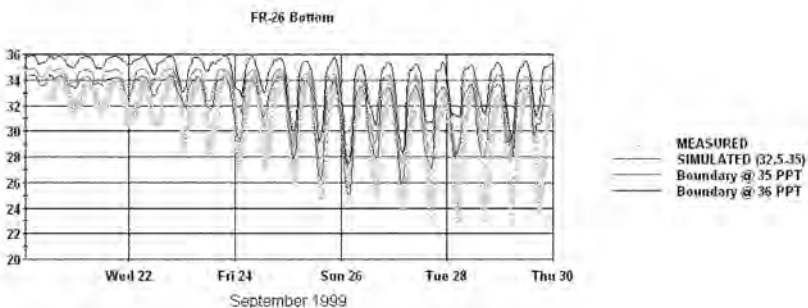


Figure 4 – Salinity Comparisons at FR-26 at the Bottom

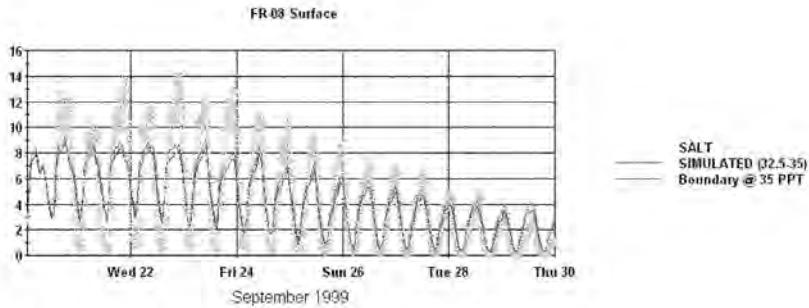


Figure 5 – Salinity Comparisons at FR-08 at the Surface

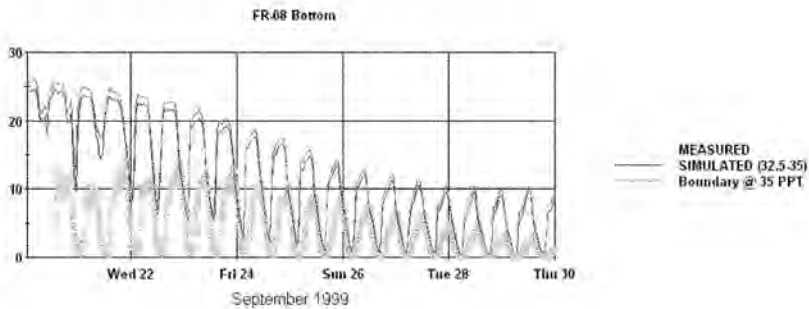


Figure 6 – Salinity Comparisons at FR-08 at the Bottom

b. Dissolved oxygen saturation 95 to 105% versus 90%

**RESPONSE 2b:** The water quality model calibration used an offshore dissolved oxygen boundary condition was approximately 6 mg/L for August 1999 (USEPA TMDL water quality model, Greenfield, 2004). Sensitivity tests were run for August 1999 calibration input. The dissolved oxygen boundary variations were set up as +/- 15%. The estimates of 10th and 50th percentiles were used for evaluation of the sensitivity. Tetra Tech agrees with 95-105% that was proposed for consideration by the Interagency WQ Team. 105% will be close to the used in sensitivity tests value (7 mg/L). The sensitivity analysis shows that the influence of the offshore D.O. boundary positive variation is most significant for bottom layers of downstream stations FR-02 (+ 13%), FR-04 (+ 8-9%), FR-06 (+6-8%), FR-21 (+ 5-8%), and FR-22 (+3-6%). The boundary effect becomes insignificant after FR-22. Surface layers of the model demonstrate low sensitivity to offshore D.O. boundary concentration variations. For these reasons, Tetra Tech is comfortable adjusting the downstream boundary condition from 90% to 95% of saturation.

c. Temperature

**RESPONSE 2c:** Summer (July-Sept.) mean surface temperature values were discussed at the offshore boundary in the range 28.0-28.5 degrees C from the "World Ocean Atlas." For

comparison, mean surface temperature at Sabsoon R2 was calculated to be 27.6 degrees for 1999-2002. For the EFDC model, the temperature data from Station R2 were applied as the ocean boundary condition. These data were not available for the calibration period, only later time periods, so a harmonic sine curve with a least squares fit was used to develop a seasonal temperature boundary. For the 1999 model year, summer (July-Sept.) surface temperatures averaged 27.0 degrees. We do not believe that altering the temperature boundary condition would improve the calibration.

d. Larry Neal gave info "World Ocean Atlas 2001" with data

**RESPONSE 2d:** Tetra Tech used the "World Ocean Atlas" data in the discussions in 2a, 2b, and 2c.

e. CBOD decay rate – confirmed 0.5 multiplier on ocean cells

**RESPONSE 2e:** Tetra Tech confirmed that a 0.5 multiplier was used in the ocean cells ( $j = 8$  to 15) and then adjusted back to 1 coming in the mouth of the river.

**COMMENT 3: [C] Surface salinity:**

a. Model appears to under predict surface salinity on the Front River. How does this impact the marsh succession modeling? The EFDC will output salinity for the neural net application, which feeds the marsh succession model. Right now, the neural net is using the USGS gages located between the Talmadge Bridge and I-95, located on Front and Back Rivers. These gages are considered to be mid-depth. The EFDC model is predicting salinity well at the bottom and at mid-depth but under predicting salinity at the surface.

**RESPONSE 3:** The model does under predict surface salinity in the Front River. Our response is discussed in 2a dealing with the offshore boundary. We do not believe it is related to the boundary, but rather related to the amount of mixing along the navigation channel. For the upper stations near the wildlife refuge, the model predictions match the data better for salinity peaks. For the marsh succession modeling, the EFDC model will deliver output to the Model to Marsh (M2M), which in turn, will deliver output to the Marsh Succession Model. Tetra Tech has developed a linkage with the M2M that passes model predicted deltas of salinity and water level in an output file. Originally, the M2M was using only the USGS gaging stations, but now uses additional sites. The specific locations and vertical layers (k-index) are described in the Table 1 below. K-index of 1 is the bottom layer and K-index of 6 is the surface layer.

Table 1 – Locations of Output for M2M Application

| No. | Name        | I-index | J-index | K-index |
|-----|-------------|---------|---------|---------|
| 1   | 'WL8840'    | 14      | 127     |         |
| 2   | 'WL8920'    | 14      | 95      |         |
| 3   | 'WL8979'    | 39      | 114     |         |
| 4   | 'WL8977'    | 13      | 59      |         |
| 5   | 'WLGPA10'   | 26      | 96      |         |
| 6   | 'WLGPA11'   | 14      | 113     |         |
| 7   | 'WLGPA11r'  | 14      | 106     |         |
| 8   | 'WLGPA12'   | 26      | 117     |         |
| 9   | 'WLGPA12r'  | 26      | 113     |         |
| 10  | 'WLGPA13'   | 31      | 123     |         |
| 11  | 'Sal8840'   | 14      | 127     | 4       |
| 12  | 'Sal89784'  | 39      | 114     | 4       |
| 13  | 'Sal8920'   | 14      | 95      | 4       |
| 14  | 'Sal89791'  | 30      | 106     | 4       |
| 15  | 'SalGPA10'  | 26      | 96      | 6       |
| 16  | 'SalGPA11'  | 14      | 113     | 1       |
| 17  | 'SalGPA11r' | 26      | 106     | 1       |
| 18  | 'SalGPA12'  | 26      | 117     | 1       |
| 19  | 'SalGPA12r' | 26      | 113     | 6       |
| 20  | 'SalGPA13'  | 31      | 123     | 1       |

**COMMENT 4: [A & B] Ebb flows and currents:**

a. Under prediction of the ebb flows and currents on the Little Back and Back Rivers

**RESPONSE 4:** Tetra Tech agrees that we are still under predicting the ebb flows only during spring tides. During neap and mid-tides, the model captures the flood and ebb flows well. During the spring tides, when we have a larger variation in water level from high to low tide, there is a significantly larger volume of water draining the estuary (ebbing) that the model is not capturing. We believe this is related to additional storage in the system in the marsh areas, irrigation ditches (Lucknow Canal), groundwater zones, etc. We are not sure why and have been comparing the measurements to explain where the additional water is coming from. We added more marsh storage to the model and did not see an improvement in our ebb flows. There is a longterm monitoring plan being developed by the federal agencies that will entail measuring continuous flow at the Front, Middle, and Little Back Rivers to improve our knowledge of the flow regime in the upper part of the estuary.

**COMMENT 5: [A] Water level at SR-17 on the Upper Savannah River**

- a. Potential of adding marsh storage areas upstream of I-95 Bridge
- b. Show comparisons at the USGS Hardeeville gage (show plot)

**RESPONSE 5:** Discussion of the EFDC model calibration raised the issue of the discrepancy in water surface elevation (stage) predictions at SR-17, which is an upstream site in the Savannah River, approximately 14 miles upstream of I-95. The model calibration under predicted stage and over predicted the magnitude of tidal oscillation, shown in Figure 7. It was hypothesized that the model was not accounting for the effects of marsh storage in the upper Savannah River (above I-95 Bridge). It was found that creating five marsh cells in the upper river dampens the tidal oscillation to the approximate range (~0.15 m or 0.5 ft) shown in the data (Figure 7). Furthermore, by increasing the bottom roughness on the Savannah River upstream of I-95, the baseline stage was increased resulting in an improved calibration at this site (Figure 8). The additional stage calibration in the upper Savannah River does not change the overall salinity results in the harbor. Based on the discussion and recommendations at the October 26 meeting, Tetra Tech will alter the EFDC model to improve the water surface elevation calibration in the upper Savannah River.

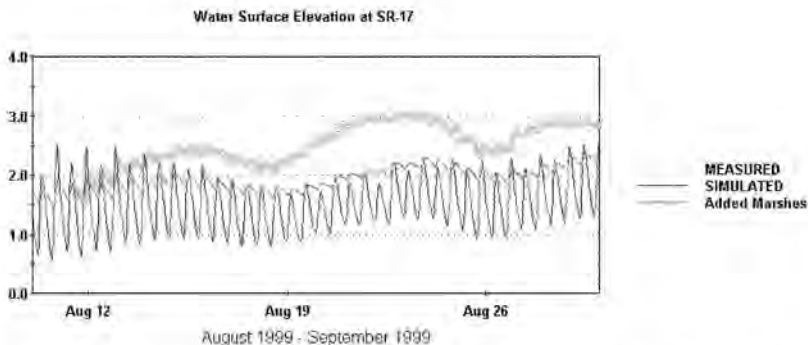


Figure 7 – Water Level at SR-17 with added marsh areas compared to May 2005 calibration

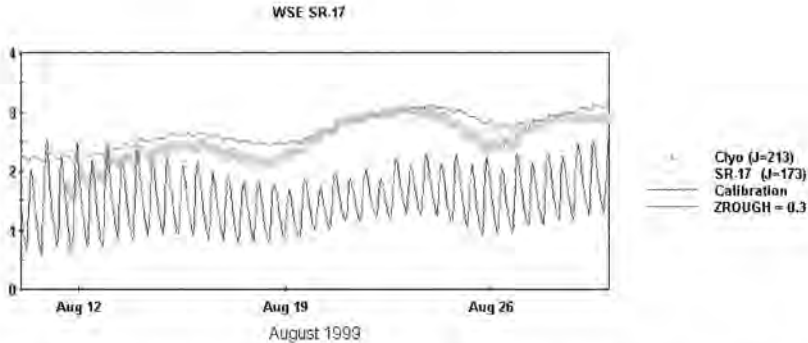


Figure 8 – Water Level at SR-17 with added marsh areas and added roughness on the Savannah River compared to May 2005 calibration

**COMMENT 6: [C & A]** Global versus source-specific BOD decay rates

a. Sensitivity of calibration

b. Sensitivity on allocation scenarios (more for TMDL)

**RESPONSE 6:** Tetra Tech has preliminarily setup two runs. The first run was a grouping in WASP according to the LT BOD results (decay rates). We used the WASP7 option that allows with three BOD classes and put the dischargers in the following categories:

- $K = 0.02$  per day (IP, Wilshire)
- $K = 0.05$  per day (Marshes, Fort James, Smurfit, President Street)
- $K = 0.07$  per day (Hardeeville, Garden City, Travis Field, Upstream, and Ocean)

The second run was done to split a large discharger such as the IP paper mill into a labile (fast reacting) and refractory (slow reacting) load category. CBOD decay rates were reassigned in following order:

- $K = 0.06$  per day (Marshes, Upstream and Ocean, all point sources except IP)
- $K = 0.2$  per day (IP 15% of discharge) = labile load
- $K = 0.02$  per day (IP 85% of discharge) = refractory load

Results of both scenarios showed no change in the calibration of the time series plots and minor changes in the calibration statistics. For demonstration purposes, the second run is shown below. Figures 9 through 11 show the same results as the May 2005 report calibration. In summary, the single rate approach will be used for deepening impacts. EPA will address the use and sensitivity of multiple BOD decay rates in the TMDL allocation scenarios. Conclusions of these runs can be summarized by salinity is still the dominating factor for DO deficit (Stations FR06 and FR22).

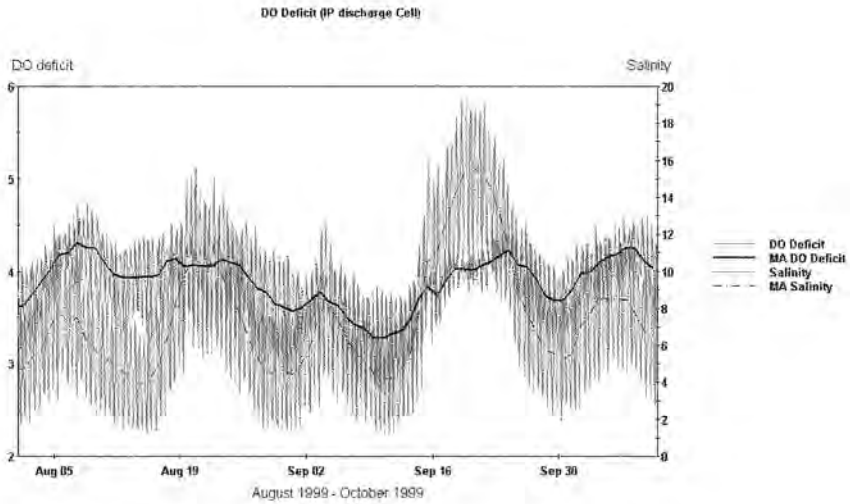


Figure 9 – DO deficit versus salinity at IP discharge (MA = Moving Average)

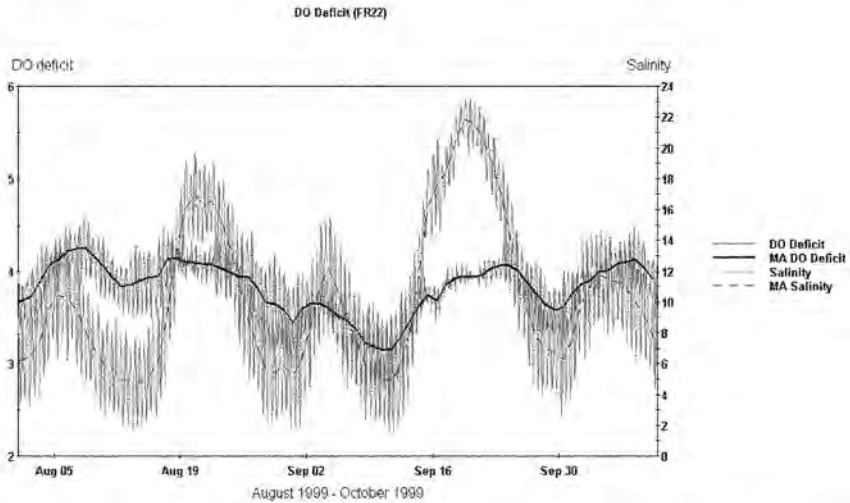


Figure 10 – DO deficit versus salinity at FR-22, downstream of IP Discharge (MA = Moving Average)

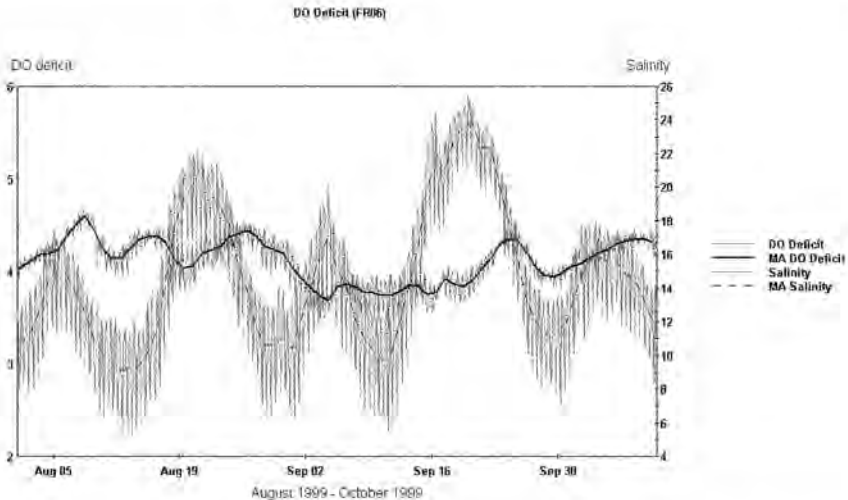


Figure 11 – DO deficit versus salinity at FR-06, downstream of IP discharge near Talmadge Bridge (MA = Moving Average)

**COMMENT 7: [A]** Check all point sources and heat loads, especially Plant MacIntosh (Harbor Committee will verify).

**RESPONSE 7:** We have not been able to verify the heat loads from MACTEC to date. From the previous comments, it appears that the flow used for Plan MacIntosh is lower than it should be. If the flows are adjusted higher, the delta temperature would be reduced to maintain their current heat load. The heat load table will be added to the report. Tetra Tech will contact Bob Scanlon and the Harbor Committee to verify.

**COMMENT 8:** [none] BOD loads from Corps' confined dredged sediment placement sites in SC and potential impacts on dissolved oxygen (future TMDL issue)

**RESPONSE 8:** No response needed at this time, may be included in the future as a TMDL issue. The clarification of the issue is presented in DHEC's June 2005 letter on the model review. The USACE will also collect data in these areas in the future.

**COMMENT 9: [A]** Grid convergence test:

- Show results of the TMDL grid with the same depth;
- Show results on TMDL grid, enhanced grid, and convergence grid on the same plots;
- Show comparisons on the Middle and Little Back Rivers;
- Perform moving average of results to reduce tidal noise; and
- Quantification of grid convergence test results.

**RESPONSE:** In the May 2005 report, Figure A-2 shows bottom salinity at Houlihan Bridge, while Figure A-3 shows the surface salinity for comparison of Enhanced Grid and Convergence Grid results. The "slightly greater stratification" phrase should be modified to indicate that slightly less salinity (difference is more apparent at surface) is observed in the Convergence



Grid results. Quantification of the convergence grid test results has been performed and is presented in the following table (Table 2). Model spin up (15 days) has been excluded from these statistics.

Table 2 – Quantification of the Convergence Grid Test Results

| Site  | Layer   | Enhanced Grid<br>Average<br>Salinity (ppt) | Convergence<br>Grid Average<br>Salinity (ppt) | Average<br>Difference<br>(ppt) | Average<br>Percent<br>Difference |
|-------|---------|--------------------------------------------|-----------------------------------------------|--------------------------------|----------------------------------|
| FR-09 | Bottom  | 27.27                                      | 26.83                                         | -0.43                          | -1.6%                            |
| FR-09 | Surface | 6.78                                       | 5.69                                          | -1.09                          | -16.2%                           |
| SR-17 | Bottom  | 0.005                                      | 0.006                                         | 0.001                          | 21.9%                            |

A plot of the daily average salinity difference and percent difference at FR-09 Bottom shows no consistent trend of difference (no divergence with time), shown in Figure 12 and the minor difference in system response for each grid may depend more on hydrologic or tidal conditions.

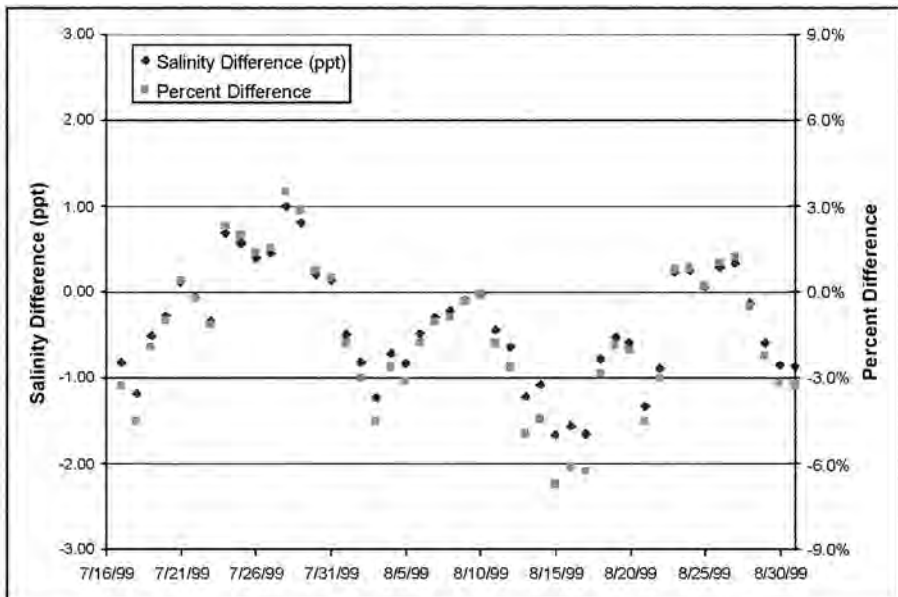


Figure 12 – Salinity and Percent Difference of Grid Convergence Results

The TMDL grid with equal bathymetry should not be compared because the surface area of the grid does not exactly match the enhanced or the convergence grid. The convergence grid is useful because the grid cells can be collapsed back to regenerate the enhanced grid. This could not be done with the TMDL grid.

**COMMENT 10: [B & C]** Delay in EFDC model salinity results at US F&W Dock comparisons of model versus data

**RESPONSE 10:** The model review group observed that the EFDC model shows a delay of salinity attenuation after high intrusion events in the Little Back River in the vicinity of the F&W Dock (USGS 021989791). Preliminary comments concerning the February 2005 draft EFDC model calibration described how the draft model completely flushed in the Little Back River (salinity dropped to zero in every tide cycle). The implementation of marshes in the final EFDC model calibration results in greater salinity retention in general. Attempts were made to modify the marsh parameters and dimensions to reduce the retention of salinity more within the range of measured data, however, no improvements from the draft calibration have been observed concerning this issue. Figure 13 below shows salinity at F&W Dock in the draft May 2005 calibration (without marshes) and in the final May 2005 calibration with marsh salinity retention.

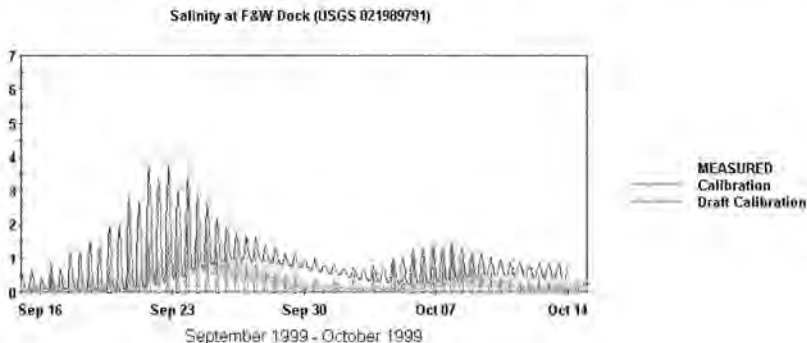


Figure 13 – Salinity and US F&W Dock with and without marshes

**COMMENT 11: [A]** Clearer description of 1999 versus 2002 bathymetry and why the 2002 bathymetry data is representative of 1997 through 2003 conditions in the harbor

**RESPONSE 11:** The 2002 and 1999 datasets were compared by analyzing cross-sections between the two surveys at many locations. Although there were some differences in alignment of the cross-sections, there was not a difference between the two surveys. Also, the survey data are grouped and averaged according to the model grid cell, and there was not a difference between 1999 and 2002 once this averaging occurred. Since dredging is a continuous operation in the navigation channel from year to year, the goal was to have a bathymetry that represents the current channel configuration, or depth, since the last deepening in 1994. It was determined that the 1999 and 2002 annual surveys are interchangeable in the model grid and best represent the existing (calibration) conditions. This text in the report has been modified.

**COMMENT 12: UA/SA Analysis:** The group concluded that the inability to run the models over a 7-year duration was the result of synthetic data that was developed to fill in a data gap around December 2000. The group concluded that the inability of the model to run over the entire 7-year period of data does not reflect on the structure of the model or its performance, and should not be a consideration of the model's usefulness for its intended purposes of predicting impacts of the Savannah Harbor Expansion Project, developing a dissolved oxygen TMDL, or permitting point source discharges.

**RESPONSE 12:** Tetra Tech agrees the 7-year run is important but in no way reflects on the stability of the model. In Section 11 of the report, Tetra Tech comments on the results of the Uncertainty Analysis. Tetra Tech performed stability and mass balance tests with the model. The model was crashing during mid-December because there was not enough water in the Little Back River during this event. The high tide on Dec 17, 2000 was only 4 feet (compared to usual 6 to 8 feet) and the low tide on Dec 19, 2000 was -2 feet (compared to usual 0 to -1 feet). See Figure 14 below for a plot of the same time period at the St. Simons Island NOAA tide gage. This proves the event was a real phenomenon and later USGS reported that the Fort Pulaski data during this time period have been checked and are real data, not synthetic data as previously discussed. The TMDL grid ran through this period because the Back and Little Back Rivers were deeper (Tetra Tech updated the bathymetry based on the 2004 USGS survey data). Therefore, Tetra Tech believes it is not a stability issue, but rather a reality issue. The model will not run when the river bed is dry, and it is believed that parts of the upper system were very shallow (or dry) during this time period.

It is evident that sections of the Back and Little Back Rivers go dry during extremely low flows and low tide range (as documented in Dec 2000). Tetra Tech has since modified the PSER.inp (time series water level boundary file) by adjusting 10 data points out of 245,280 (0.004%), which was only 5 hours out of a 7-year record, and the model now runs for 7 years without going dry. Since December 2000 is not a critical period for the modeling scenarios, we felt justified altering the water level boundary for these limited data points. Figure 15 shows the altered water level boundary file for this time period.

In summary, the data during December 2000 proved to be valid and a real phenomenon occurred during this time period (some kind of offshore wind or pressure system). Since the 7-year model run became a critical issue among the Stakeholder Evaluation Group (SEG), Tetra Tech modified the water level boundary file to receive a continuous 7-year model run.

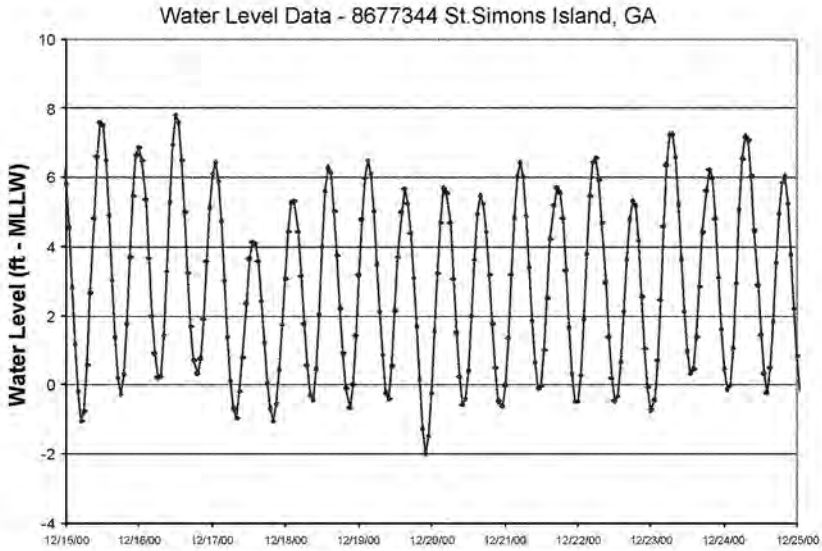


Figure 14 – Water level data measured at St Simons Island NOAA gage

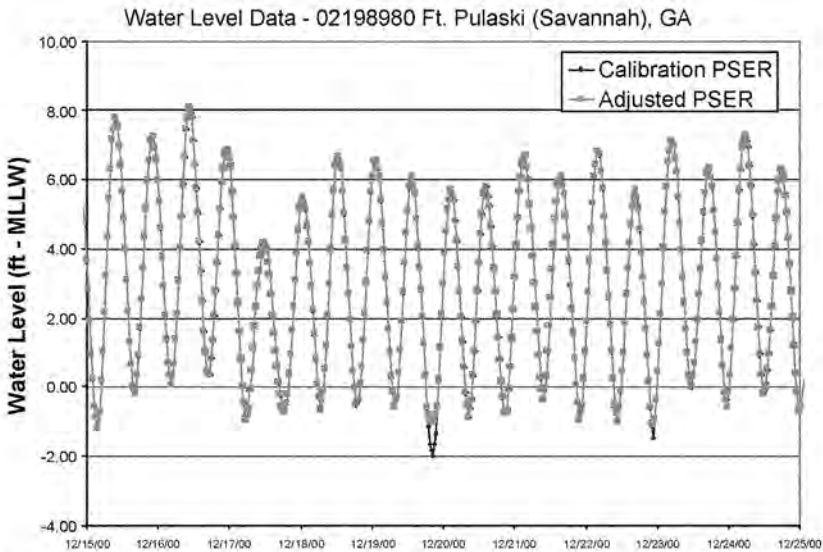


Figure 15 – Modified water level data for model boundary

**FOR CONTINUATION OF HOUSE DOCUMENT 112-153**

**SAVANNAH HARBOR EXPANSION PROJECT  
CHATMAN CO., GEORGIA & JASPER CO., S. CAROLINA:  
FINAL GENERAL RE-EVALUATION REPORT AND  
ENVIRONMENTAL IMPACT STATEMENT**

**SEE PART 3**