National Park Service
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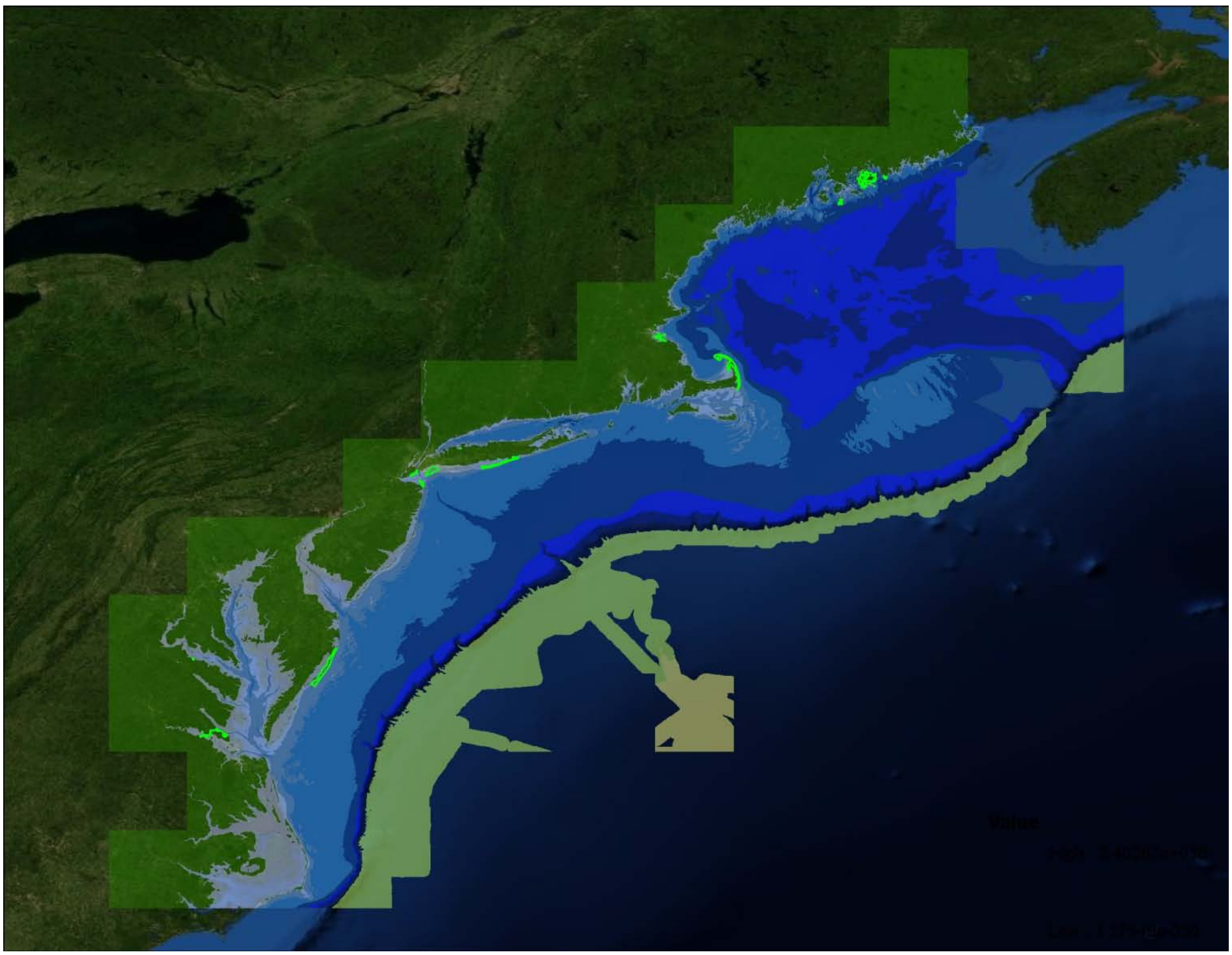
Natural Resource Stewardship and Science

Priority Data on Marine and Estuarine Resources within Northeastern National Parks

Inventory and Acquisition Needs

Natural Resource Report NPS/NCBN/NRR—2013/612



ON THE COVER

Coastal relief model for the northeastern U.S. overlaid with boundaries of National park units (bright green).
Photograph prepared by Tracy Hart using data from the NOAA National Geophysical Data Center, U.S. Coastal Relief Model, Retrieved 12 April 2011, http://www.ngdc.noaa.gov/mgg/coastal/crm.html

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This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

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Contents

Figures

Figures (continued)

Page

Figures (continued)

Page

Tables

Page

Tables (continued)

Page

Appendices

Abstract

The purpose of this project was to guide development of a strategy for the inventory and mapping of submerged natural resources associated within 10 coastal parks of the National Park Service (NPS) Northeast Region (NER; see Table 1). Priority data needs were identified by the NER Ocean Stewardship Task Force. The majority of the NER priority data needs involve the biotic, chemical, and geological characterization of the seabed. Taken collectively, this demands a consistent and unified approach to habitat classification. The Coastal and Marine Ecological Classification Standard (CMECS) is endorsed by the Federal Geographic Data Committee (FGDC-STD-018) for classifying ecological units in coastal and marine environments, and is recommended as a framework for acquiring and organizing NER data. We prepared an inventory of existing data on priority marine and estuarine natural resources within the ten NER coastal parks. This report describes the data and information sources relevant to each park and identifies gaps in available data. Overwhelmingly and uniformly across all parks, the most pressing needs are consistent, high-resolution bathymetry and seafloor characterization data. Approaches for acquiring these data using an integrated, multi-resolution sampling framework are recommended.

Acknowledgments

This report was completed with assistance from many people and organizations. Beth Johnson, Charles Roman, and Sara Stevens within the NPS Northeast Region conceived of this project and worked with NPS Natural Resource Managers to identify the types of data needed to manage marine and estuarine resources within coastal parks; this list of priority data needs framed this project and guided it from beginning to end. We thank Brad Barr of NOAA National Marine Sanctuary Program and Gary Davis of NPS Ocean Programs for early project reviews that forced us to consider data resolution, minimum mapping units, and classification standards in evaluating and acquiring marine resource data; their foresight led to a more thorough product. We are indebted to Roland Duhaime and Rebecca Bannon of University of Rhode Island Environmental Data Center for their tremendous geospatial expertise and overall good humor in preparing the marine resource inventory database, and to GIS personnel and Resource Managers at each of the coastal National Park units in the Northeast Region for identifying additional datasets for inclusion in the inventory. We also thank Aimee Mandeville of University of Rhode Island, Matt Nixon of IAP World Services, and Frank Pendleton of USFWS Rose Atoll Marine National Monument and National Wildlife Refuge, for their time and guidance with GIS databases and preparation of GIS products. We are indebted to the National Park of American Samoa for providing the office space and Internet access that made it possible for one of our authors to work on this project from a Pacific isle located thousands of miles from the Northeast Region. We greatly appreciate the careful reviews of an earlier version of this report provided by Amanda Babson of NPS Northeast Region and Jeffrey Cross and Thom Curdts of NPS Oceans and Coastal Resources; their recommendations improved the report substantially. We also thank Robin Baranowski, NPS Northeast Coastal and Barrier Network, for copy editing and formatting the report. Finally, we are exceptionally grateful to Sara Stevens, Program Manager of the NPS Northeast Coastal and Barrier Network, for her leadership and guidance of this project; her commitment to providing information to coastal parks and resourcefulness in program administration were invaluable to all phases of this report.

List of Acronyms

AASG	Association of American State Geologists
ACAD	Acadia National Park
ADCP	Acoustic Doppler Current Profiler
AGDS	Acoustic Ground Discrimination System
ASIS	Assateague Island National Seashore
AUV	autonomous underwater vehicle
AVS	acid volatile sulfide
BAG	Bathymetry Attributed Grid
BHC	hexachlorocyclohexane
BHICS	Boston Harbor Intertidal Classification System
BIOMAR	Marine Habitat Classification for Britain and Ireland
BOHA	Boston Harbor Islands National Park Area
CACO	Cape Cod National Seashore
CAD	computer-aided design
CBOS	Chesapeake Bay Observing Program
CCAP	Coastal Change Analysis Program
CIR	color-infrared
CMECS	Coastal and Marine Ecological Classification Standard
COLO	Colonial National Historical Park
CONMAP	Atlantic Continental Margin Mapping Project
CO-OPS	Center for Operational Oceanographic Products and Services
CORS	Continuously Operating Reference Stations
CSC	Coastal Services Center
CTD	conductivity, temperature, and depth
CVI	coastal vulnerability index
CWA	Clean Water Act
CZM	Coastal Zone Management
DDE	dichlordiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DEC	Department of Environmental Conservation
DEM	digital elevation model
DEP	Department of Environmental Protection
DEQ	Department of Environmental Quality
DMA	Defense Mapping Agency
DMF	Division of Marine Fisheries
DNR	Department of Natural Resources
DO	dissolved oxygen
DOT	Department of Transportation
EAARL	Experimental Advanced Airborne Research Lidar
EDC	Environmental Data Center
EEZ	exclusive economic zone
EFH	essential fish habitat
EMAP	Environmental Monitoring and Assessment Program
eMOLT	Environmental Monitors on Lobster Traps

List of Acronyms (continued)

EOEA	Executive Office of Environmental Affairs
EPA	Environmental Protection Agency
ERDAS	Earth Resources Data Analysis System
ESI	Environmental Sensitivity Index
EUNIS	European Union Nature Information System
FEMA	Federal Emergency Management Agency
FGDC	Federal Geographic Data Committee
FIIS	Fire Island National Seashore
GATE	Gateway National Recreation Area
GEBCO	General Bathymetric Chart of the Oceans
GEWA	George Washington Birthplace National Monument
GIS	Geographic Information System
GPS	Global Positioning System
GRI	Geologic Resources Inventory
IRMA	Integrated Resource Management Applications
JALBTCX	Joint Airborne Lidar Bathymetry Technical Center of Expertise
KML	Keyhole Markup Language
MAIA	Mid-Atlantic Integrated Assessment
MARACOOS	Mid-Atlantic Regional Association Coastal Ocean Observing System
MARP	Marine Aggregate Resources Project
MassGIS	Massachusetts Office of Geographic Information
ME DIFW	Maine Department of Inland Fisheries and Wildlife
ME DMR	Maine Department of Marine Resources
ME GS	Maine Geological Survey
MGS	Maryland Geological Survey
MLW	mean low water
MMS	Minerals and Mangement Service
MMU	minimum mapping unit
MORIS	Massachusetts Ocean Resources Information System
MWRA	Massachusetts Water Resources Authority
NAC CESU	North Atlantic Coast Cooperative Ecosystem Studies Unit
NALCC	North Atlantic Landscape Conservation Cooperative
NARS	National Aquatic Resource Survey
NBS	National Bureau of Standards
NCA	National Coastal Assessment
NCBN	Northeast Coastal and Barrier Network
NCSU	North Carolina State University
NDBC	National Data Buoy Center
NEFSC	Northeast Fisheries Science Center
NER	Northeast Region
NERACOOS	Northeastern Regional Association of Coastal and Ocean Observing Systems
NERRS	National Estuarine Research Reserve System
NERRSCS	National Estuarine Research Reserve System Classification Scheme
NETN	Northeast Temperate Network

List of Acronyms (continued)

NGDC	National Geophysical Data Center
NHESP	Natural Heritage and Endangered Species Program
NJDEP	New Jersey Department of Environmental Protection
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NWI	National Wetlands Inventory
NWIS	National Water Information System
NWLON	National Water Level Observation Network
NWQMC	National Water Quality Monitoring Council
NWS	National Weather Service
PAHs	poly-aromatic hydrocarbons
PCBs	poly-chlorinated biphenyls
PDF	portable document format
PDOP	Positional Dilution of Precision
PORTS	Physical Oceanographic Real-Time System
PSP	paralytic shellfish poisoning
REMUS	Remote Environmental Monitoring UnitS
ROV	remotely operated vehicle
RTK	Real Time Kinematic
SAHI	Sagamore Hill National Historic Site
SAIR	Saugus Iron Works National Historic Site
SAV	submerged aquatic vegetation
SCHEME	System for Classification of Habitats in Estuarine and Marine Environments
SEM	simultaneously extracted metals
SHOALS	Scanning Hydrographic Operational Airborne Lidar Survey
SPI	Sediment Profile Imaging
SSURGO	Soil Survey Geographic
STORET	STOrage and RETrieval
SUNY	State University of New York
TIFF	tagged image file format
TOC	total organic carbon
UNEP	United Nations Environment Program
USACOE	U.S. Army Corps of Engineers
USFWS	U. S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VIMS	Virginia Institute of Marine Science
WCMC	World Conservation Monitoring Centre
WCP	Wetlands Conservancy Program
WHOI	Woods Hole Oceanographic Institution

Introduction

Enhanced conservation and management of submerged marine and estuarine resources is moving to the forefront of National Park Service (NPS) planning at the national and regional levels. The NPS Ocean Park Stewardship Task Force and Action Plan (2007a) commits to science-based conservation of marine resources and calls for increased understanding of marine ecosystems and human interactions, restoration of impacted resources, and new measures to enhance park resource management efforts. To implement this plan in the Northeast Region (NER), a regional Ocean Stewardship Task Force developed the Northeast Region Ocean Park Strategic Plan (NPS 2007b). For some coastal parks in the NER, a very significant portion of the total park area is defined as submerged (FIIS 75%, GATE 67%, ASIS 66%, CACO 38%; see Table 1 for park abbreviations), yet there is a lack of basic information on natural resources within these submerged lands. Therefore, the NER Ocean Park Strategic Plan established a goal to inventory and map natural and cultural resources within the submerged boundaries of the region's coastal parks. Basic information about the components, characteristics, and processes affecting submerged resources is fundamental to the NPS mandate of conserving and managing the resources under its stewardship. Maps and inventories for submerged resources are critical for coastal park managers to develop policies for resource protection, to identify restoration and research needs, to provide for recreation use, to assess habitat condition and measure performance, and to design monitoring programs.

This report summarizes existing data on marine resources relevant to NER parks and suggests strategies for acquiring additional high-priority data. The 10 coastal parks included in this effort (Table 1) span from Maine to Virginia and fall within two separate networks of the NPS Vital Signs program – the Northeast Temperate Network (NETN) and the Northeast Coastal and Barrier Network (NCBN). Recently, NPS has initiated natural resource condition assessments at most of the parks identified for this study. Several assessments have been completed (ACAD, Vaux et al. 2008; FIIS, McElroy et al. 2009; ASIS, Carruthers et al. 2011) and others are at various stages of development. These assessments describe ecosystem condition and potential threats for entire park watersheds, and they have yielded numerous instances where the condition of marine resources and threats to their integrity could not be assessed due to inadequate information. Similarly, while not focused specifically on marine and estuarine resources, Geologic Resource Evaluations (NPS 2012a) and Scoping Meetings conducted at NER coastal parks underscore gaps in available hydrogeologic data, shoreline maps, seafloor topography, and benthic surficial and stratigraphic maps (see *National and Regional Datasets—Hydrogeologic framework*). These information gaps hinder the parks' ability to address high priority concerns such as erosion, wetland protection, shoreline change, benthic habitat and species management, offshore development, climate change, dredging, and sediment budgets. To date, inventories of marine and estuarine resources within NER parks have not kept pace with inventories of terrestrial resources. This report intends to guide the extension of the NPS inventory effort to the extensive submerged marine and estuarine portions of NER coastal parks. Fort Monroe National Monument, at the mouth of Chesapeake Bay, Virginia, was added to the national park system in November, 2011, following completion of the research and analysis for this report. Although information pertaining to Fort Monroe specifically is not described here, some of the data sets summarized for GEWA and COLO contain data collected in lower Chesapeake Bay that would be relevant to this new coastal National Monument.

Table 1. Park abbreviations, states, and Networks for the NER National Parks. Networks are the Northeast Temperate Network (NETN) and the Northeast Coastal and Barrier Network (NCBN).

Park Abbreviation	State(s)	Network	Park Name
ACAD	ME	NETN	Acadia National Park
BOHA	MA	NETN	Boston Harbor Islands National Park Area
SAIR	MA	NETN	Saugus Iron Works National Historic Site
CACO	MA	NCBN	Cape Cod National Seashore
FIIS	NY	NCBN	Fire Island National Seashore
SAHI	NY	NCBN	Sagamore Hill National Historic Site
GATE	NY	NCBN	Gateway National Recreation Area
ASIS	MD, VA	NCBN	Assateague Island National Seashore
GEWA	VA	NCBN	George Washington Birthplace National Monument
COLO	VA	NCBN	Colonial National Historical Park

For all coastal parks there is a gradient from terrestrial environments (e.g., coastal forests, grasslands, dunes), to intertidal environments (e.g., salt marshes, sand beaches, rocky shores), to subtidal environments (e.g., seagrass beds, mud bottoms, shellfish beds). This report focuses on the permanently submerged (subtidal) portions of coastal parks within ocean, estuary, and coastal bay areas. In the NER coastal parks these submerged lands occur primarily at shallow depths (less than 30 m).

The principal objective of this project was to guide development of a strategy for acquiring subtidal marine and estuarine inventory and mapping information relevant to the NER parks. Our approach toward realizing this objective involved:

1. determining an organizing framework for NPS marine data;
2. evaluating technological approaches to data acquisition;
3. identifying existing data sources and summarizing existing data;
4. evaluating existing data to identify gaps between those available and those required by NER resource managers;
5. developing recommendations for addressing information gaps.

Priority Data Needs

In the spring of 2006, NER coastal park managers convened a work group to identify the types of inventory and mapping data needed to characterize submerged marine and estuarine resources in coastal parks. The list of highest priority needs to emerge included physical and biological components (Table 2). These inventory and mapping data are considered fundamental to goals of effectively managing and conserving the marine and estuarine natural resources within parks of the NER. Achieving these goals is also predicated upon the ability to adequately resolve natural resource features in a spatial context, with adequate spatial resolution to afford park managers an ability to make meaningful assessments of resource condition.

Bathymetric maps, analogous to terrestrial-based topographic maps, provide essential information on depth and depth contours within the submerged environment. Nautical charts provide bathymetry for navigational purposes, but they are not routinely updated and often have poor resolution in the shallow waters that characterize park submerged areas. Modern high-resolution bathymetry is needed for modeling water circulation and sediment transport, designing facilities and dredge operations, and characterizing and mapping habitats. Bathymetric data can be displayed as two-dimensional contours (e.g., nautical charts) or three-dimensional representations (e.g., digital elevation models, relief models).

Basic hydrographic information includes wave climate (height, direction, periodicity), tide characteristics (range, phase, tidal current), and circulation patterns (currents). The movement of water directly or indirectly affects all aspects of marine and estuarine areas. Specific uses of hydrographic information include oil and contaminant spill response, facilities design and placement, dredge planning, managing visitor use, protecting cultural resources, and planning of habitat restoration projects.

The hydrogeologic framework of a park consists of the geologic foundation, geomorphology, shallow stratigraphy, and the major surface and groundwater pathways. At more northern sites such as ACAD and BOHA this includes an understanding of bedrock geology, whereas at the barrier island parks this includes a characterization of subsurface geologic structure to depths below the seafloor of 20 m or more. Information on geomorphology is essential to understand historic, present-day, and potential future landscape conditions, including coastal vulnerability to acute storm events and chronic effects of sea-level rise. Shallow stratigraphic information is important to visualize the stability of surficial substrates, an especially key consideration in shallow water because of the susceptibility of these areas to storm surge. Finally, hydrogeologic framework data also enable identification and quantification of reservoirs of sand for beach nourishment or natural transport processes and evaluations of nutrient inputs to the coastal zone (Hart et al. 2010).

Table 2. Highest priority inventory and mapping needs for submerged marine and estuarine resources identified by NER managers, March-April 2006.

Data Themes	Data Types	Management Applications
Oceanographic and Physiographic Components		
Bathymetry	• Water depth	• Predicting oil and contaminant spill response • Facilities design and placement • Dredge planning and management • Assisting in defining visitor protection and use • Coastal change modeling • Planning of habitat restoration • Cultural resource management
Hydrography	• Wave height, direction, and periodicity • Tide range and phase • Circulation patterns and currents	• Dredge planning and management • Facilities design and placement • Evaluating vulnerability to contaminants/pollutants • Contaminant /oil spill response • Habitat characterization and restoration planning • Sediment transport modeling • Cultural resource management
Hydrogeologic framework	• Surface and groundwater pathways • Bedrock geology and shallow stratigraphy (characterization of subsurface geologic structure perhaps to depths of 20 m)	• Facilities planning • Evaluating groundwater movement and zones of nutrient or contaminant inputs • Evaluating breach potential on barrier islands • Quantifying offshore reservoirs of sand for beach nourishment activities • Assisting with prediction of cultural site locations
Surficial geology	• Sediment grain size • Sediment organic content • Subaqueous soils mapping and seafloor characterization	• Planning, evaluating, and managing dredge activities and facilities placement • Evaluating vulnerability to contaminants/pollutants • Habitat characterization and restoration planning • Sediment transport modeling • Cultural resource management
Sediment contaminants	• Distribution and concentration of EPA priority pollutants (metals and organic contaminants)	• Baseline for natural resource damage assessments • Evaluating public health concerns • Dredge planning
Water chemistry and water quality	• Water temperature • Salinity • Chlorophyll concentration • Pathogens	• Visitor use protection at bathing beaches • Understanding harmful algal blooms and macroalgal nuisance species • Characterizing habitats and understanding species occurrences • Documenting freshwater inputs and potential nutrient-laden waters
Biological Components		
Submerged habitats and biological communities	• Seagrass distribution maps • Macroalgae distribution maps • Benthic community maps and species inventories	• Natural resource damage assessments baseline • Evaluating coastal development proposals • Identifying critical fish spawning areas • Identifying shellfish beds of recreational and commercial importance • Planning for habitat restoration • Identification of potential shorebird habitat • Identification of invasive species • Identification of potential habitat for rare species

Surficial geology includes grain size and organic content within the top several cm of the seafloor. Subaqueous soils mapping provides information through soil profiles that may extend over 1 m in depth from the sediment surface. The Natural Resources Conservation Service (NRCS) is presently engaged in a pilot initiative in Rhode Island to extend traditional terrestrial soils mapping into the submerged environment (MapCoast 2008). These types of data are critical for planning dredging operations and designing facilities, understanding sediment transport processes, and managing cultural resources. Surficial sediments reflect the energy of the environment and are a primary control on the distribution and diversity of benthic habitats and fauna (Hastings et al. 2005); therefore, information on substrate characteristics is an important component for classifying submerged habitats.

Surficial sediment data are also critical to evaluating vulnerability of sediments to contamination from pollutants. Knowledge of the distribution and contaminant level of U.S. Environmental Protection Agency (EPA) priority pollutants is required for all NPS submerged marine resources. These pollutants include metals and organic contaminants such as poly-aromatic hydrocarbons (PAHs) and poly-chlorinated biphenyls (PCBs). Inventory of these contaminants is essential as a baseline for natural resource damage assessments, and for evaluating and managing public and ecological health risks.

Basic water-chemistry and water-quality parameters include water temperature, salinity, chlorophyll (as an indicator of water column primary production), pathogens, nutrients, dissoleved oxygen, and other constituents. These data are necessary for protection of visitor health at bathing beaches, understanding harmful algal blooms and macroalgal nuisance species, documenting freshwater inputs and nutrient loading, characterizing habitat, and understanding species occurrences.

Submerged habitats are the areas of ocean, estuarine, and coastal bay environments inhabited by particular organisms. These habitats include the geologic and sedimentary environments (i.e. the surficial geology) and any biogenic structure created by sessile marine organisms. Submerged habitats in the NER may be unvegetated (e.g., sand, mud, shell beds, cobble, rock) or vegetated (e.g., seagrass beds, macroalgae). Biological community maps are required that depict benthic community species composition and indicator species associated with various bottom types. Prominent examples include seagrass and macroalgal distributions. Submerged habitat maps and species inventories are necessary for a variety of resource management purposes including the establishment of a baseline for natural resource damage assessments in response to oil and other contaminants, evaluating responses to coastal development proposals, identifying critical fish spawning areas and significant shellfish resources, identifying invasive species encroachment, assessing habitat condition, and evaluating and predicting responses to natural and anthropogenic disturbances.

The data types identified above represent the base-level information that is necessary to inventory and assess submerged resources in coastal parks. Comparison and synthesis of these data are complex, however, due to the varying methods employed to acquire different types of data and due to the varying resolutions, sampling intensities, and geographic extents of the resulting datasets. Ultimately, a thorough understanding of resource condition requires descriptions of not only the quantity and types of resources present, but also the distribution and extent of these resources. Therefore, in addition to inventorying, mapping of submerged resources is an essential component of the acquisition and analysis of high priority data. Mapping of ecosystem components within a spatial context, and their display within a Geographic Information System (GIS) format, enables visualization and comparison of the geographic extents of inventoried submerged resources. Spatial representation facilitates the identification of spatial and temporal trends, gaps in data coverage, and potential correlations between data types. Jeffrey Cross, chief of the Ocean and Coastal Resources Branch of NPS, summarizes that “spatial display and analysis is the most efficient and cost-effective way for park managers to use complex natural resource information” (Cross 2012). For example, ecological, oceanographic, socio-economic, cultural, and remote sensing datasets for several NPS Pacific and Caribbean marine park units have been integrated in a geospatial database, providing a common spatial framework for visualizing and comparing information available on natural and cultural resources (NOAA NCCOS 2012).

Marine Ecosystem Classification

Assessing and comparing the condition of submerged resources across the NER requires a common framework for describing complex and often disparate datasets. Marine classification schemes provide approaches for assigning names to unique combinations of abiotic and biotic ecosystem characteristics. A consistent marine classification scheme would offer a framework for acquiring and organizing data that are of high priority for managing NER marine and estuarine resources (Table 2). Numerous schemes exist for classifying the ocean environment and its associated biological communities (Table 3). Implicit in each is a system for categorizing the seabed into units that can be mapped and monitored at resolutions appropriate for the scale of relevant features and the management questions. Each of the existing classification schemes was developed as a means for categorizing specific data types, from purely geological facies to floral and faunal benthic communities, populations, or species. We evaluated existing marine ecosystem classification systems with respect to their suitability for characterizing both geophysical and biological attributes within NER parks (Table 3). Our evaluation is included in Appendix 1.

Marine inventory and mapping projects within National Park units nationwide have relied on various classification schemes. In temperate regions, several of the NOAA Coastal Services Center benthic habitat mapping projects have involved resources within National Park units. Among these are benthic habitat mapping projects along the Olympic Coast of Washington State (Olympic Coast National Marine Sanctuary and Olympic National Park), the San Francisco Bay region (areas of Golden Gate National Recreational Area and Point Reyes National Seashore), and the Texas coastal seagrass mapping efforts (Padre Island National Seashore). However, no standardized classification scheme was applied across these projects. Similarly, the U.S. Geological Survey (USGS) has participated in cooperative marine benthic mapping projects in Hawaii and Glacier Bay, where different ad-hoc classifications and data displays were applied. In Florida, the state’s System of Classification of Habitat in Estuarine and Marine Environments (SCHEME) has been applied to marine habitats along the west coast of Everglades National Park. Although each of these individual classification projects has clear local value to NPS units, none is a strong candidate for adoption throughout the NER because they do not achieve standardization, do not address all of the applicable data types, and/or are not fully relevant to NER resources.

Table 3. Marine seabed characterization and habitat classification schemes reviewed for applicability in managing priority NPS data.

Coastal and Marine Ecological Classification Standard (CMECS)	
FGDC 2012a,b	
NOAA National Estuarine Research Reserve System Classification Scheme (NERRSCS)	
Kutcher et al. 2008	Habitat and land cover classification scheme for the National Estuarine Research Reserve System
Kutcher et al. 2005	Original recommendation for a comprehensive habitat and land use classification system for the National Estuarine Research Reserve System
NOAA Coral Ecosystem Classification Scheme	
NOAA 2008a	
Digital Potential Marine Benthic Habitat Maps Using a Coded Classification Scheme (Greene Scheme)	
Greene et al. 2007	Synthesis and update
Greene et al. 1999	Original classification scheme for deep seafloor habitats
Classification of Marine Sublittoral Habitats (Valentine Scheme)	
Valentine et al. 2005	
Classification of Wetlands and Deepwater Habitats of the United States (Cowardin)	
Cowardin et al. 1979	
The Marine and Estuarine Habitat Classification System for Washington State	
Dethier 1990	
A Classification System of Marine and Estuarine Habitats in Maine: An Ecosystem Approach to Habitats	
Brown 1993	
Marine and Estuarine Ecosystem and Habitat Classification	
Allee et al. 2000	
Our Living Oceans Benthic Habitat Classification System	
Brown 2002	
Florida System for Classification of Habitats in Estuarine and Marine Environments (SCHEME)	
Madley et al. 2002	
Marine Habitat Classification for Britain and Ireland (BIOMAR)	
Conner et al. 2004	
European Union Nature Information System (EUNIS)	
Davies and Moss 2004	

Similarly, several marine ecosystem classification schemes have been used extensively in the northeastern U.S. In particular, Valentine et al. (2005) developed a method for classifying seafloor environments in the northwest Atlantic Ocean specifically, with categories based upon seabed substrate type, sediment dynamics, and the degree of physical and biological complexity. Greene et al. (2007) developed a scheme to classify seafloor habitats throughout the marine realm, including both sub-arctic and tropical latitudes, and this scheme has been applied in and evaluated for use in the NER. Both approaches use acoustic and ground-truth data, and resulting geophysical (or substrate type) maps, as the basis for benthic habitat classification. Neither approach encompasses water column or intertidal environments. Relevant to the NER, these and other existing schemes were reviewed for use in Massachusetts waters by Lund and Wilbur (2007) and for use throughout the Gulf of Maine region by McDougall et al. (2007), and Valente et al. (2007) tested several classification schemes using pre-existing data for Boston Harbor and Western Massachusetts Bay.

A uniform approach for characterizing and classifying marine environments is fundamental to understanding resources at national and regional scales. Ultimately, a service-wide marine classification scheme would facilitate compilation and comparisons of inventory, remote sensing, mapping, and monitoring data derived from dispersed locations using different technologies and resolutions. The Coastal and Marine Ecological Classification Standard (CMECS) provides a national framework for consistent descriptions of coastal and marine ecological features (FGDC 2012a). The Federal Geographic Data Committee (FGDC) endorsed CMECS as a national standard following a lengthy period of testing and input from a wide variety of stakeholders (FGDC 2012b). As described more fully below, CMECS evolved from earlier versions (Madden and Grossman 2004, Madden et al. 2005, 2008) based on input from experts in a variety of disciplines. NPS assisted in refinement of this standard through participation on the FGDC CMECS Working Group (Dr. Jeffrey Cross, Chief of NPS Ocean and Coastal Resources Branch, email communication, 6-21-2011). Within the NER, versions of CMECS were piloted and assessed for applicability at FIIS (Schumenchenia and King 2010) and GATE-Jamaica Bay (Nigel Shaw, GIS Coordinator for NPS NER, email communication 6-13-2011). In addition, classification of estuarine and marine environments in the northwest Atlantic (Maine to Virginia) using CMECS is underway through the North Atlantic Landscape Conservation Cooperative (NALCC 2012). Scheduled for completion in 2013, this project will apply CMECS at regional, intermediate, and local scales. The high-resolution application will classify benthic information for Boston Harbor at 1:5000 scale, thus will be particularly relevant to BOHA.

CMECS encompasses many of the capabilities essential for describing marine resources important to NPS on a national scale (Moses et al. 2010a). Importantly, CMECS is a “dynamic standard” to allow continued enhancements. It is expected that use and application of CMECS will identify necessary additions and adjustments to the standard. New descriptive units can be added to CMECS through a formal review process that will not require repeating the FGDC standards approval (FGDC 2012a). To this end, CMECS developers are building a community of practice to enhance implementation, share experiences, and further improve the classification standard (discussed by Dr. Garry Mayer, Senior Scientist with NOAA National Marine Fisheries Service - Office of Habitat Conservation, and CMECS Development Team member, during a CMECS workshop at the Coastal and Estuarine Research Federation Conference, 11-6-2011). Because CMECS is dynamic, has been endorsed as the national standard by FGDC, and incorporates many capabilities important to NPS, we recommend it as a foundation for organizing information about coastal and marine features in the NER parks. Summaries of other existing classification schemes are in Appendix 1.

Coastal and Marine Systems Ecological Classification Standard (CMECS)

CMECS was developed by NOAA and NatureServe as a national framework for organizing information on coastal and marine environments (FGDC 2012a). It is applicable on spatial scales of less than 1 m^2 to thousands of km^2 and can be used in littoral, benthic, and pelagic zones of coastal, estuarine, and open ocean systems. CMECS units align with existing FGDC standards for classifying wetlands (Cowardin et al. 1979) and vegetation (FGDC 2008). It was informed also by many of the common, pre-existing classification schemes, such as a well-established seafloor classification system (Greene et al. 2007) and various regional and state-level classifications (e.g., SCHEME in Florida, Madley et al. 2002; marine and estuarine habitat classification for the state of Washington, Dethier 1990). By building on and integrating these existing classification schemes, CMECS is expected to support a variety of local and regional applications while allowing integration of information at very large scales.

CMECS classifies marine and coastal environments into biogeographic and aquatic settings that are differentiated by features influencing the distribution of organisms and by salinity, tidal zone, and proximity to the coast. Four underlying components describe attributes of environmental units and biota within each setting: (1) the Water Column Component describes open water settings in terms of vertical layering, water temperature and salinity, hydroforms, and biogeochemical features; (2) the Geoform Component describes the major geomorphic and structural characteristics of the coast and seafloor; (3) the Substrate Component describes the composition and size of estuary bottom and sea bed materials, encompassing substrates of geologic, biogenic, and anthropogenic origin; and (4) the Biotic Component identifies the composition of floating, suspended, and benthic biota. CMECS components include standard physicochemical, spatial, geological, biological, anthropogenic, and temporal modifiers to further characterize ecological units.

CMECS is an ecological classification scheme rather than a mapping standard; CMECS unit definitions represent ecological variation across the range of occurrence rather than expression in a given area at a given time, and there is no minimum mapping unit or technological constraint inherent in the unit definitions. Nonetheless, a primary application of the system will be classifying mapping data, and it will undoubtedly be used also to guide the planning of mapping projects. Just as occurs with vegetation or wetland maps based on FGDC classification standards, the CMECS classification units can be ascribed to locations with defined geographic boundaries. Additionally, CMECS components can be mapped independently and combined in a GIS to integrate different types of information, analogous to the combination of information from independent land form, land cover, and soil classifications to describe a terrestrial parcel of land. The decision whether and how to integrate components should be based on project information needs, type of source data, and spatial exclusivity between units being integrated (FGDC 2012a).

Meeting NPS Inventory and Mapping Needs

A substantial amount of the NER Priority Data (Table 2) is best collected using an integrated sampling approach and organized within the conceptual framework of an ecological classification scheme (*sensu* CMECS) using a GIS. These data types include bathymetry, seafloor surficial geology, shallow stratigraphy, sediment contaminants, and submerged habitats and biological communities. Although the remaining data types (hydrography, certain hydrogeologic framework data, water chemistry, and water quality) are not necessarily acquired using this integrated sampling approach, they too benefit from the CMECS framework organized within a GIS.

An integrated approach to sampling typically involves initial collection and processing of underwater acoustic data to measure bathymetry and characterize bottom and sub-bottom substrates, and corresponding discrete samples (e.g., bottom cores, grab samples, photographic or video images, or sediment profile images) for ground-truthing (see *Data Acquisition* for methodology). From these data, interpretive basemaps can be derived of seafloor topography, bathymetry, geophysical characteristics of the substrate, and habitats. Data developed to ground-truth acoustic data can be further used to map the spatial distribution of biological communities and individual species. Seabed characterization and habitat classification maps generated this way have further utility for informing and stratifying the design of discrete sampling programs for other metrics (e.g., sediment contaminant concentrations) and for understanding surficial geology-biology relations. This integrated sampling approach thus serves as a comprehensive and efficient means to address many of the priority data types within a spatial context.

Strategies for acquiring information on priority data types both within and outside of this integrated survey will be driven by the spatial density, depths, and spatial and temporal variability of the features of interest and the intended use of the data, as well as the time, funding, and resources available for data acquisition. For example, due to the scale over which advection and mixing of water parcels occurs, the sampling intensity needed to characterize water chemistry in an area of coastal ocean, bay, or estuary is much coarser than would be required for determining the composition of benthic communities, which may change over scales of less than 1 m. Therefore, approaches for meeting inventory and mapping needs will vary across data types and across park units.

Spatial Resolution and Minimum Mapping Units

Information on bathymetry and the geophysical nature and biological cover of the seafloor is fundamental to managing marine resources and provides the foundation for all subsequent data acquisition. Bathymetry and seafloor characterization data should be collected at a resolution no coarser than the features of priority interest; therefore, resource management needs ultimately dictate approaches to data collection. Various acoustic platforms have different acoustic "footprints," or the area of the seafloor that is mapped by the survey instrument at any given location. Acoustic seabed characterization will be a major component of the NPS marine inventory and mapping efforts, and the costs associated with seafloor mapping could differ markedly depending upon the spatial scale of resource classification. It is important to note that once data have been acquired, the resolution can be artificially reduced to meet coarser delineation scales, but never increased. The Interagency Working Group on Ocean and Coastal Mapping is strongly promoting the importance to "map once, use many times" (JSOST 2008).

We recommend that NPS follow suit and collect bathymetry and seafloor characterization data at the highest resolution affordable in order to make them as broadly useful as possible.

A minimum mapping unit (MMU) is the smallest discrete unit identified on resource maps; areas smaller than the MMU will have been aggregated into units the size of the MMU. For NPS NER, we recommend a MMU no larger than 100 m^2. This size is somewhat smaller than the 300 m^2 commonly used for aerial mapping of seagrass beds (Finkbeiner et al. 2001), but it is not uncommon for acoustic mapping within marine protected areas (e.g., Kendall et al. 2005, Gibbs et al. 2007). The NER coastal parks range in area from 3 ha (SAIR) to over 19 km^2 (ACAD) and a 100-m^2 MMU is a reasonable scale for habitat mapping within parks at both ends of the size gradient.

Acquisition of seafloor characterization data at a 100-m^2 resolution is suitable for many habitat management needs. However, NER management objectives also address individual natural and cultural features. These features may include archeological objects; objects related to fishing, aquaculture, vessel operation or navigation; or natural features such as individual boulders. If the presence and condition of these small (ca. 1 m^2) natural and cultural features are to be included among the project objectives for acoustic surveys, then data must be collected with complete bottom coverage and spatial resolution no coarser than this scale. Acquiring data at high spatial resolution also increases the ability to identify small features (e.g., sand waves and rock crevices) that may be important for characterizing particular biological communities or habitats and allows for delineating and mapping at fine spatial scales if needed. Finally, high-resolution data support certain resource protection needs, such as assessing environmental damage resulting from vessel groundings or illicit activities.

Therefore, we recommend acquiring acoustic data at a resolution of 1 m^2 wherever possible. This is a pivotal point with respect to all further decisions the NER will make concerning data acquisition and mapping strategy. Although not all management applications require the ability to resolve individual features at this level, data at a resolution of 1 m^2 are required for management of point features and they provide a means to address management issues related to seafloor habitat at scales finer than the 100-m^2 MMU.

Data Acquisition

Technologies are summarized for acquisition of integrated bathymetry and seafloor data. These data are fundamental to organizing and interpreting information on the other priority data types, and our gap analysis showed these data to be the most broadly needed among the NER parks. Many methods-manuals for acquiring data outside this integrated sampling approach (i.e., on hydrography, surface and ground-water paths, and water chemistry and water quality) are readily available through government agencies (e.g., Strobel and Heitmuller 2001, USGS 2012a) and the scientific literature (e.g., Kramer et al. 1994, Emery and Thomson 2001).

Integrated Bathymetry and Seafloor Characterization

A variety of technologies are commonly employed for acquiring bathymetry and seafloor characterization (i.e., surficial sediments, habitats, and biological communities) data. Optical remote sensing (satellite or airborne) of seabed features is constrained in aquatic systems by the depth to which the light waveform can penetrate the water, and of the NER priority data types, only seagrass mapping is routinely performed in this region using optical methods due to water clarity characteristics throughout the coastal park waters. Most bathymetry and seafloor characterization in the NER will be done by interpreting data acquired by acoustic surveying and ground-truthing techniques.

Bathymetry is, itself, a priority data type for NER marine resource management, and it is also an integral component of substrate characterization and benthic habitat mapping. Since most modern approaches to seabed characterization and habitat mapping are based upon interpretation of acoustic backscatter data, and since these backscatter data are generated from hydrographic instruments designed to map bathymetry, there is a functional link between acquisition of these data types.

Although each acoustic technology functions somewhat differently, in general, characteristics of the backscatter of acoustic signals (or pings) directed at the seafloor provide a means of distinguishing areas of different biophysical character. Bathymetry is also calculated from these acoustic signals based on time of return. Discrete samples (such as bottom cores, photographic or video images, sediment grabs, or sediment profile images) are used to associate the various acoustic signatures with sediment characteristics and/or habitat type.

The most widely available source of bathymetry data comes from NOAA hydrographic surveys, and these data are indeed adequate to meet a portion of the identified NER management needs (Table 2). A particularly useful example is the NOAA Estuarine Bathymetry Project[234] (NOAA 2007), which generated bathymetric Digital Elevation Models (DEMs) for 70 of the nation's 130 large identified estuaries. The DEMs are based upon numerous data points from the NOAA hydrographic surveys (3.2 million soundings in the Chesapeake Bay for example), and were generated at two scales, the finer of which provides coverage in 7.5- by 7.5-minute blocks (30-m by 30-m data spacing). Full or partial coverage is available for many of the NER parks (i.e., COLO, GEWA, FIIS, SAHI, GATE, CACO, BOHA, and ACAD). These bathymetric data and derivative DEMs are adequate to address some of the NER management applications (e.g., contaminant spill response planning, visitor use, and safety), but are insufficient for others. Applications such as sea-level monitoring and coastal change modeling may require low spatial resolution, but demand excellent vertical datum control and high temporal resolution. Spatial resolution requirements increase for applications like dredge planning, substrate characterization, and habitat mapping, and are highest for activities related to cultural resource management, such as shipwreck and archeological resource preservation.

Methods

From the late 1800s until the 1930s, navigational charting of ocean depth by the NOAA National Ocean Service (NOS) was performed exclusively with lead-line sounding techniques. Although mechanical sounding of the seafloor is no longer used for scientific mapping purposes, these data survive in NOAA NOS bathymetric data sets and are still used for many hydrographic applications. Modern bathymetric and seafloor characterization data are collected using single-beam Sound Navigation And Ranging (sonar), several forms of swath-sounding sonar (multibeam, interferometric, and sidescan), and Light Detection and Ranging (lidar). These methods are described briefly below. Detailed comparisons of the technologies for characterizing seafloor substrates and producing maps exist in the scientific literature (e.g., Davies et al. 2001, Kenny et al. 2003, Coggan et al. 2007; Todd and Greene 2007; Anderson et al. 2008). In addition, recent workshops have addressed survey methods for nearshore marine habitat mapping within National Parks on a national scale (Moses et al. 2010 a, b), in NER National Parks (Hart et al. 2010), and in Gulf of Maine waters (Hart and Grabowski 2009), and field tests of different acoustic methods have been conducted in NER parks (Shumchenia and King 2010, Psuty and Silveira 2010, Gayes et al. 2010). Thorough descriptions and comparisons of technological approaches to seafloor characterization can be found in these reports and the references therein.

Single-beam sonar

Starting in the 1930s and extending through the 1990s, NOAA NOS hydrographic surveys were conducted using single-beam sonar. Single-beam sonar systems emit sound pulses from a transducer into the water column. The pulses are emitted in a beam toward the seafloor directly below the transducer at specific intervals, and bathymetric information is derived from the time of the acoustic return as captured by the transducer.

Around the same time that NOS was migrating away from single-beam sonar for hydrographic surveys, Acoustic Ground Discrimination Systems (AGDS) were starting to be developed using the same equipment. AGDS are based on the principle that acoustic reflectance from the seafloor produces meaningful information about seabed characteristics. The return echoes detected by the transducer are used to compute seabed rugosity (roughness) and induration (hardness). Combined with adequate ground-truthing, these metrics can be used to discriminate different benthic habitat types. AGDS are commercially available from a number of vendors, are moderately priced, and are reasonably affordable to deploy and operate. In addition, the analysis of single-beam data is relatively straight forward. The major disadvantage of single-beam systems is incomplete coverage of the bottom as the data are derived from directly under the survey vessel only. This necessitates considerable interpolation for producing seafloor maps, which introduces error. The area of bottom ensonified by the single-beam echosounder, or the acoustic footprint, is determined by properties unique to the transducer, the beam angle, and the water depth; the size of the footprint increases with water depth, resulting in poor resolution in deep water (Foster-Smith et al. 2001). Thus single-beam systems are best used in very shallow water (less than 3 m; Hart et al. 2010) and continue to be regularly employed by researchers for mapping bathymetry and seabed characterization. Single-beam systems can be mounted on AUVs and even jet skis to map bathymetry in very shallow waters and surf zones that pose navigational hazards.

Multibeam sonar (beam-forming swath)

For hydrographic applications, multibeam sonar began replacing single-beam systems in the 1980s and has been a primary bathymetric survey tool since the 1990s. Multibeam sonar systems collect bathymetric soundings in a swath perpendicular to the vessel track. This is accomplished by a series of single-beam transducers mounted along a boom, or by electronically forming a series of transmit-and-receive beams within transducer hardware (Hughes-Clarke et al. 1996). For hydrographic studies, multibeam sonar systems are integrated with data from the Global Positioning System (GPS) and onboard inertial motion sensors. The former provides the basic positional information, while the latter allows for very precise correction based upon the instantaneous orientation, or “attitude”, of the transducer. Acoustic backscatter intensity data are collected simultaneously with bathymetry and are used to interpret bottom characteristics such as grain size and roughness from multibeam data. Application of this technology for seabed characterization and benthic habitat mapping is becoming increasingly common.

The width of survey swaths using multibeam sonar is influenced by the system's design, but is geometrically coupled to the distance between the sonar system and the seafloor. Swath widths can be as great as eight times the water depth. In shallow water of less than 4 m, however, the usable swath width is usually limited to about three times the water depth (Gostnell 2004). Thus a common application of multibeam sonar is in waters 10 m to 30 m deep (Hart et al. 2010). The implication for NPS NER is that, for significant areas of the larger barrier island parks where water depth is less than 2 m (FIIS, ASIS, CACO), the swaths would be limited to less than 6 m wide. Small swath widths greatly increase survey time and cost and reduce the efficiency of data acquisition in shallow water because survey tracks of the research vessel or autonomous vehicle need to be so closely spaced.

Interferometric sonar (phase-discrimination swath)
Interferometric sonar is the leading-edge technology in bathymetric mapping and benthic characterization (Gostnell 2004, Baldwin et al. 2004). Like multibeam sonar, interferometric sonar is also a "swath-sounding" technique that measures depth in a swath extending perpendicular from the vessel. However it is not a beam-forming system. Instead of dividing the acoustic swath among a set of transducers, with each assigned a portion of the total angle, interferometric systems discriminate the angle of backscatter by measuring the phase offset of acoustic returns at a set of precisely spaced "listening" transducers. Sometimes referred to as phase-discrimination, this technology provides similar information to multibeam sonar (bathymetry plus backscatter for seabed characterization), but with the advantage of better angular resolution in the outer portion of the swath (where beam angles are acute) and greater swath width. Interferometric systems can achieve swath widths of up to 15 times the water depth, which is considerably greater than multibeam systems (White and Jegat 2007), and versions are commercially available for mounting to small boats and autonomous underwater vehicles (e.g., Raineault et al. 2011). The wide swath relative to the water depth makes interferometric sonar particularly advantageous in nearshore waters, where use has increased in the past decade (White and Jegat 2007). In very shallow waters the achievable swath width for bathymetry is limited by the scattering properties of the bottom: as the incident angle of the sound gets small, most of the sound ends up scattering away from the source rather than back to the receivers. The result of this is a higher signal-to-noise ratio (S/N) at the outer edges of the swath and a swath width equivalent to that of single-beam sonar in very shallow waters (less than 3m; Hart et al. 2010).

Sidescan sonar
Sidescan sonar is a swath-sounding technique that is typically operated by towing an instrument package or "tow-fish" over the study area. The tow-fish is equipped with a linear array of transducers emitting a fan of acoustic energy pulses that sweeps the seafloor from directly under the tow-fish to either side, perpendicular to the vessel track. The backscatter from these acoustic pulses is captured by those same transducers and provides information on the characteristics of surficial sediments and outcropping strata. The frequency of the outgoing acoustic energy determines the aerial coverage and the resolution. Although depth is measured below the tow-fish, sidescan alone has limited use for bathymetric studies because positional control of the tow-fish is inadequate. Instead, sidescan sonar backscatter data are used to map the texture of surficial sediments (induration and rugosity of the seafloor), for qualitative characterization of the seabed, and for object detection and recognition. The geometry of the beam emitted from the transducer relative to the bottom results in relatively large acoustic shadows cast by relatively small objects on the seafloor (Kenny et al. 2001, 2003), so that sidescan sonar is undisputed

among the remote sensing tools for object detection (Brisette and Hughes-Clarke 1999). Sidescan sonar can therefore be an essential instrument in projects requiring the discrimination of natural or cultural features. In shallow waters, sidescan sonar is currently a primary tool for regional substrate type mapping because it has a wider swath than multibeam at shallow depths (Hart et al. 2010). Sidescan sonar can also be mounted on an autonomous underwater vehicle (AUV) for shallow-water mapping. This approach provides very clear sonograph imagery because the transducer is decoupled from surface chop, swell, or a tow cable, and because the AUV maintains a near-constant altitude above-bottom (Hart et al. 2010).

Sub-bottom profiler

Sub-bottom acoustic profiling is the standard technique for characterizing the shallow structural and sedimentological composition under the seafloor. Reviews of this technology are provided by Waddington and Hart (2003), Mesdag (2007), and references therin. Sub-bottom profilers emit relatively low-frequency pulses vertically downward through the water column. Part of the sound pulse penetrates the sediment/water interface and is reflected back from boundaries between sub-bottom layers of different acoustic impedance, and this reflected energy is used to build an image of the sub-bottom environment. The vertical resolution, or ability to resolve closely spaced horizons, is inversely related to the depth of penetration into the sea bottom, and penetration depth depends on the acoustic frequency and the type of sediment through which the signal travels. There is a great variety of sub-bottom profiling systems commercially available, distinguished by the duration and frequencies of sonic pulses and whether they are emitted at single, dual, multiple discrete, or swept frequencies. Selection will be guided by project specifications, water depth, and seafloor characteristics. Sub-bottom profilers are typically towed, although hull-mounted systems are preferable in shallow water (less than 5 m deep) for improved positional accuracy (Waddington and Hart 2003). Sub-bottom and sidescan sonars may be co-located within the same tow-fish during integrated acoustic assessments. As with all acoustic systems, groundtruthing with discrete samples is essential to ensure accurate interpretation of sub-bottom characteristics.

Lidar

Airborne lidar (light detection and ranging) was first conceptualized in the 1960s for topographic studies. Since then, several operational bathymetric systems have also been developed using this technology. Two systems have been widely applied to shallow marine bathymetric mapping: the NASA EAARL (Experimental Advanced Airborne Research Lidar) system and the U.S. Army Corps of Engineers (USACOE) SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey). Lidar employs active sensors that transmit laser pulses to a target and record the time for those pulses to return to a receiver. In practical application, laser energy is lost to refraction, scattering, and absorption as the pulse travels from the aircraft to the seafloor and back. The combination of these losses limits the maximum detectable depth. Optical water clarity and bottom type are the factors most limiting the maximum detectable depth, and operable depth ranges are generally on the order of 1.5 to 3 times the Secchi depth (Irish and Lillycrop 1999, Irish and White 1998, Nayegandhi et al. 2006). Airborne lidar has been used successfully to map marine benthic habitats in clear water (e.g., seagrasses and sand in Florida, Wang and Philpot 2007), but lidar systems may have limited use for bathymetric mapping in the northeast, where summertime algal blooms and turbidity restrict surveys to poor-weather months, affecting flight scheduling, data quality, and costs (Hart et al. 2010). In addition, a recent analysis of lidar-derived digital elevation models for BOHA, ASIS, and CACO found the operational accuracy of the lidar data to be considerably lower than was specified (Murdukhayeva 2012), which suggests prudence and independent accuracy analysis when using lidar topographic data. NPS has been collaborating with the USGS to acquire dense lidar topographic data at several NER parks (ASIS, FIIS, GATE) using the EAARL system. Although the submerged lands of NER parks are generally very shallow, these estuarine systems are also characteristically turbid, and to date lidar has not been conclusively demonstrated as capable of mapping to all depths within the park boundaries. However, for very shallow bathymetry, airborne lidar provides a useful tool for covering gaps between the shallow extent of acoustic surveys and mean low water, thus providing a means to develop seamless topographic/bathymetric maps extending from terrestrial to offshore boundaries. This is particularly relevant to parks with low tidal amplitude where high tide does not afford sufficient navigational depth for acoustic surveys.

Recommendations

The preferred method for bathymetric mapping and seafloor characterization depends on the depth range over the survey area and survey objectives, in terms of resolution, object detectability, the size of the area to be mapped, and percent coverage (Kenny et al. 2003, Hart et al. 2010, Moses et al. 2010a). In addition, available time, funding, and technological resources will dictate methodology. In deep waters (greater than 10 m), multibeam or interferometric sonar offer the ability to acquire bathymetry and bottom texture (via acoustic backscatter) data simultaneously while identifying benthic resources at a resolution sufficient to address all resource management needs (1 m^2). In relatively shallow waters (3 m to 10 m), interferometric sonar offers a substantially greater swath width than multibeam, thus providing the maximum efficiency for obtaining simultaneous bathymetry and backscatter data. Sidescan sonar can be used in either of these depth ranges for seafloor characterization, but must be coupled with another systemfor bathymetry mapping, and sidescan sonar is often combined with other acoustic methods to enhance object detectability. In very shallow waters (depth less than 3 m), single-beam AGDS can provide simultaneous bathymetry and backscatter data, or often a combination of single-beam bathymetry and sidescan sonar is used. Single-beam AGDS may be particularly attractive for NER parks with very shallow or small areas of submerged marine and estuarine resources (e.g., COLO, SAIR).

Discrete Sampling and Accuracy Assessments for Acoustic Benthic Mapping

The acoustic and lidar methods described above are indirect techniques for providing a broad-scale overview of the seafloor. A comprehensive seafloor characterization must also include fine-scale sampling data to improve the detail and accuracy of this broad-scale interpretation. A variety of physical and photographic techniques exist for such discrete seafloor sampling. These direct-sampling techniques generate high-resolution data used to ground-truth or "field check" remote sensing surveys. Ground-truth data are used to assist with manual interpretation of broad-scale data, calibrate its automated interpretation, and assess the accuracy of image analysis results. Subsamples of physical seafloor samples collected to ground-truth broad-scale assessments can also be analyzed for sediment contaminants. Discrete sampling methods for ground-truthing broad-scale benthic surveys are summarized below. Thorough descriptions are referenced and should be consulted for methodological details.

Physical sampling techniques
A wide variety of tools are available for direct sampling of the seafloor. The type of sampler is dictated by the characteristics of the substrate being described and the area, volume, and depth of the desired samples. Grab sampling devices are used to provide quantitative samples of sediments to depths of 10 to 15 cm (e.g., Mudroch and MacKnight 1994; Waddington and Hart 2003; TetraTech 2003; Poppe et al. 2005a; Mackie et al. 2007). In general, grab samplers are lowered to the seafloor on a wire suspended over the side of a boat from a winch, boom, or other support mechanism. Some grabs in current use are set in pyramidal frames (e.g., Smith-McIntyre, Day, Hamon, and Modified Van Veen grabs) that increase the stability of the grab on the seafloor, whereas others lack a frame (e.g., Ekman, Ponal, and Van Veen grabs). When the grab reaches the seafloor a release mechanism is triggered to close the grab around an intact sediment sample. Although grab samples provide information appropriate for interpreting broad-scale data on substrate surface characteristics, cores are necessary to provide ground-truth data for interpreting acoustic sub-bottom profiling (TetraTech 2003; Waddington and Hart 2003; Poppe et al. 2005a). Core samplers are hollow tubes that penetrate the substrate to collect vertical profiles of the sediment. There are various types of core samplers available (e.g., hand cores, gravity cores, piston cores, vibracores) for collecting samples up to 20 m deep. Finally, trawls and dredges can be used to sample epibenthic macrofauna (Vize and Coggan 2007). Both types of gear are towed over the substrate behind a boat; trawls are designed to skim the substrate surface and dredges are designed to dig into the top sediments. Ultimately, regardless of the specific tools employed for discrete physical sampling, common quality-assurance steps include ensuring the cleanliness of all sampling equipment, penetrating the sediment surface to the desired sampling depth, and recording the precise locations of all samples collected (Poppe et al. 2005a).

Optical sampling techniques
Optical data-acquisition techniques for ground-truthing broad-scale survey data consist of still or video imaging methods. A downward-looking camera mounted in a frame can provide plan-view photographs of the undisturbed seafloor surface at discrete locations ranging in coverage up to about 2 m^2 (Waddington and Hart 2003). Sediment Profile Imaging (SPI) works like an inverted periscope to provide vertical cross-sectional photographs (in situ profiles) of the upper 15 to 20 cm of sediments (Waddington and Hart 2003; Curtis and Coggan 2007). Computer analysis of the resulting sediment profile can yield such data as sediment grain size distribution, sediment surface relief, depth of the apparent redox potential discontinuity, and various faunal features. Underwater video cameras can be dropped over the side of a boat, mounted on a sled and towed behind a boat, mounted on remotely operated vehicle (ROV) systems, or hand-held by divers (e.g., Mitchell 2007; Beaman and Harris 2007; McLeod et al. 2007). Still and video imaging can provide descriptive, semi-quantitative, or quantitative data, depending on survey design.

Broad-scale Optical Approaches to Habitat Mapping
Although acoustic techniques, coupled with groundtruthing, are a common integrated approach for acquiring bathymetry and substrate characterization information, optical approaches to habitat mapping are also used under appropriate conditions to map nearshore benthic environments. Common optical techniques for gathering broad-scale survey data are described below.

Aerial photography

Optical remote sensing of seabed features is limited in aquatic systems by the depth to which light wavelengths can penetrate the water. Aerial photography for benthic mapping applications is constrained to the photic zone, which in nearshore environments can range from depths of less than 1 m in turbid systems to about 30 m in very clear water. It is used routinely for identifying certain benthic habitats, including seagrass meadows and shellfish beds, at scales ranging from 1:12,000 to 1:48,000. Aerial photographs are well suited for mapping habitat extent and patch distribution, but detailed characteristics such as species composition, sediment texture, or habitat quality are more difficult to assess and generally require supplemental technologies (Finkbeiner et al. 2001). Advantages of aerial photography include the visual assessment of remote areas, the relatively low cost, and frequently, the presence of a historical photographic record for comparison with current conditions (Piel and Populus 2007a). Several state-based mapping programs monitor the distribution and abundance of submerged aquatic vegetation in the vicinity of NER parks based on aerial photographic mapping (ACAD, BOHA, CACO, FIIS, ASIS, COLO, and GEWA; described in Kopp and Neckles 2009).

Finkbeiner et al. (2001) provide detailed technical guidance to aerial photography for benthic habitat mapping. Successful mapping depends on acquiring aerial photographs under optimal environmental conditions. Specifications for image acquisition address tidal stage, phenology of dominant species, sun angle, turbidity, wind, and atmospheric conditions (i.e., clouds and haze). The majority of mapping applications use color or black and white negative film, for which highly reliable standards have been developed regarding film quality, image capture, photo processing, and interpretation (Finkbeiner et al. 2001, Dekker et al. 2007). However, technological advancements have led to increased use of digital photography for habitat mapping. In particular, the availability of digital cameras in both large-format with metric-quality lenses (although expensive) and small-format with high-resolution non-metric lenses has eliminated the need for film developing and scanning for some applications (Dekker et al. 2007).

Multispectral and hyperspectral imaging

Multispectral and hyperspectral remote sensing is based on measuring the wavelength and intensity of electromagnetic radiation reflected from the seabed. Multispectral imagery is produced by sensors that measure radiation reflected within a few wide, separated sections of the electromagnetic spectrum, or wavelength bands. In contrast, hyperspectral sensors measure energy reflected at a series of numerous narrow, contiguous wavelength bands; hyperspectral images may contain 200 or more bands, providing near-continuous measurement across the electromagnetic spectrum. Consequently, hyperspectral imagery can support much more detailed image analysis with very high spatial resolution, albeit at higher costs due to the large volume of data acquired and stored and the complexity of data processing.

Thorough reviews of seafloor mapping based on multispectral and hyperspectral imagery are provided by Dekker et al. (2007), Piel and Populus (2007b, c), and Waddington and Hart (2003), and these sources and the references therein should be consulted for methodological details of data acquisition, processing, and interpretation. The various multispectral and hyperspectral sensors in current use can be categorized as either satellite or airborne systems (Dekker et al. 2007). The majority of satellite remote sensing systems use multispectral sensors. Satellite imaging can cover very large areas and a wide range of sensors are available that differ considerably in spatial, spectral, and temporal resolution. The type of features to be detected will dictate which sensor should be used in terms of the wavelength bands and pixel sizes, or ground resolution, provided. Although satellite multispectral imaging can be used to map nearshore, shallow seafloor features, optimal environmental conditions (low cloud cover, low turbidity, shallow water, minimal sun glint from sea surface) are required for electromagnetic radiation to penetrate through the water. Some of the more recent multispectral satellite systems have short revisit rates and programmable sensors (e.g., Ikonos and QuickBird commercial systems) offering more agility to target low tides, however, use in many temperate areas is still limited by environmental conditions. A small number of satellite hyperspectral systems now exist (e.g., Hyperion launched on NASA's Earth Observing-1 satellite in 2000) but they face the same environmental constraints for use in aquatic systems and lack of flexibility inherent in satellite sensors regarding timing of data acquisition. Wang et al. (2007) tested use of QuickBird-2 multispectral satellite images for mapping seagrasses in Great South Bay, NY, where seagrasses generally occupy depths less than 2 m, and found an overall accuracy of 75% in classifiying bottom as high-density seagrass, low-density seagrass, or unvegetated sand.

Airborne remote sensing offers the ability to time data acquisition to optimal environmental conditions. Although the spatial resolution depends on aircraft altitude, airborne platforms typically provide considerably greater resolution than comparable satellite sensors. Airborne imaging systems based on both multispectral and hyperspectral sensors exist. The narrow band width of hypersectral data can be applied more readily to distinguish heterogeneous benthic substrates, biota, and even vegetation condition (reviewed by Dekker et al. 2006), and sensors are increasingly packaged with sophisticated technology to increase geometric accuracy and repeatability. Dekker et al. (2007) suggest that with rapid advancements in sensor technology, processing algorithms, and computing systems, remotely sensed data will become a cost-effective method of choice for high-resolution benthic mapping.

Current use of optical habitat mapping techniques in the NER is constrained primarily by environmental conditions. However, for certain applications (e.g., seagrass mapping) optical mapping is widely used. These methods may become increasingly important to NER parks in the future as technologies continue to evolve and improve. The promise of these technologies for NER parks lies in their ability to map nearshore areas that may be difficult to access using other techniques.

Ultimately, the choice of appropriate technologies should be guided by data-acquisition needs. This overview of technologies is provided for consideration within the context of acquiring marine and estuarine resource data needed to manage NER coastal parks. The remainder of this report provides information on the data currently available to meet NER park resource management needs (Table 2) and the critical gaps in existing data sources.

Data Inventory

In order to prioritize marine inventory data for NPS acquisition, we first constructed a catalog of existing data sources that meet NPS information needs. Our goal was not to create an exhaustive inventory of all data, but rather an inventory identifying data sources that would contribute meaningfully toward NER resource management needs as identified by NER Park managers (Table 2). Existing data were therefore evaluated in terms the following criteria: pertaining to subtidal marine resources; relevant to resources inside park boundaries; recent enough to be relevant in assessing current conditions; and substantial enough in scale or extent to contribute meaningfully toward data needs for each park. Due to the inherent connections among coastal ecosystems, occasional data sets related to intertidal and terrestrial resources were included in the inventory. Similarly, due to the importance of issues such as sand budgets to a number of the NER parks, some offshore and navigation channel datasets were included in the inventory if they mapped and described resources that relate intimately to the management of park resources. Finally, if dated information provided important historical context it was included in the inventory. The bulk of the inventory was completed in early 2008. A small number of records were added in 2011 to reflect recent seafloor mapping projects in NER parks. These additions, however, do not constitute a comprehensive update of the inventory and the following descriptions of data availability may not fully reflect current status.

Structurally, the catalog is a non-relational “flat file” database containing the following sixteen information fields for each data source record.

1. Record Contributors – the person contributing or editing the inventory record
2. Data Category – from the list of priority data types
3. Data Sub-Category – from the list of priority data types
4. Park(s) – names of NER park(s) to which the data record is relevant
5. Name/Title – title of the dataset, monitoring program, GIS file, or scientific study
6. Data Format/Data Type – any of the following: spreadsheet, JPEG, PDF, Raster, Vector, Website, Report, Manuscript
7. Date(s) – time period that the dataset covers
8. General Technical Description – technical description of the data form and contents
9. Qualitative Description of Spatial Extent and Resolution – qualitative description of the data as it relates to NER needs, such as the proportion of data falling within park boundaries, number of sampling stations, distance from the park boundary if the data are outside the park.
10. GIS Work Needed – work that would be necessary to convert the data to GIS format or to create FGDC compliant metadata
11. Creation Technique – a brief description of the methods used to collect or create the data
12. Protocol Used – name of any established protocols used for data collection or processing
13. Spatial Scale or Resolution – quantitative description of the resolution such as the scale to which the data can be accurately mapped or the minimum mapping unit
14. Website – site where the data can be downloaded or where additional data or documentation can be obtained.
15. Publication Citation and Abstract – for scientific publications and reports
16. Publication Link

As each data source was identified for inclusion in the catalog, a record was created that populated as many of these fields as possible. Information to populate the fields was taken from GIS metadata, data reports, and program descriptions. Initial contributions to the data inventory were identified by communicating with GIS personnel at each of the NER parks, by searching state GIS data sources, by interrogating the NPS Data Store, and by searching for other relevant state, federal, and academic data sources. After completing a draft version, online collaboration tools were used to solicit assistance from each of the NER parks in checking for known omissions and further populating the inventory. Records were sorted by park(s) of relevance, and invitations were distributed to resource managers at each park, who, in turn, could invite the participation of government, academic, and institutional researchers known to be knowledgeable about their parks. Each collaborator could examine the online inventory and make real-time additions and edits within a shared work environment. Online questionnaires were used to facilitate the creation of wholly new inventory records. These were completed either by the invited collaborators, or were redirected to other researchers and potential data providers. The resulting inventory includes 248 discrete records, several of which represent data pooled from numerous distinct studies or programs into a single data resource.

Additionally, subsets of inventory records were flagged for immediate acquisition. A geospatial catalog of these highly relevant data was prepared for the NER parks using a file geodatabase structure within ArcMap. Prioritization for this step was given to data that were GIS ready, were entirely applicable to the priority data needs, and where visualization of the geospatial data would be helpful in evaluating information gaps. The completed inventory and geospatial catalog were used to evaluate the adequacy of existing data in meeting the needs of the NER and individual parks.

Summary of Existing Data

Datasets in the data inventory and other information products are described here and analyzed for their sufficiency in meeting NER parks' priority data needs. This analysis is based on the best available information as of the inventory's completion (early 2008), as well as more recent data records that were submitted by several parks in 2011 in response to a request for information by the authors. The recent additions to the inventory represent major datasets that have been completed since the initial inventory was concluded and are essential to the report's relevancy. These additions, however, do not constitute a comprehensive update of the inventory and do not fully reflect current status.

Appendix 2 provides a list of the data records contained in the inventory and described in this section. Each of these datasets is identified in the text by a superscript, which corresponds with a data record number within the inventory. This report also references many interpretive information products that are not included in the inventory, and are therefore not cross-referenced using superscripts. All sources of information (inventory data records and other sources) are listed in the Literature Cited.

The data descriptions are divided into two sections: (1) National and Regional Datasets; and (2) Local/Park-specific Datasets. Within each section (national/regional datasets and individual parks), information is organized by the priority data types identified in Table 2; if no relevant data (i.e., data meeting the criteria for inclusion in the inventory) were found within a particular data type, that data heading was omitted. Although the data descriptions vary markedly by data type, a number of general questions guided our data summaries. Whenever possible, datasets were analyzed in ArcGIS for their geographic coverage within park boundaries. Also of interest was the data resolution, sampling intensity, horizontal and vertical accuracy, date and time period over which the data were collected, the data source, and the purpose for collection.

Following the data summaries, a section on Gap Analysis and Recommendations provides a synthesis of the oceanographic and physiographic data types (Table 2) in terms of the quality and extent of data available for each park.

Table 16 provides a comparative rating of the quality of data available relative to park interests based on these filters and serves as a quick reference for assessing the status of data availability for each park. Datasets within the biological communities data type were deemed too disparate in terms of organisms of focus, purpose of collection, and resolution and coverage to fit within the scope and context of this analysis.

National and Regional Datasets

A number of datasets within the inventory are national products or pertain to the entire Northeast Region or specific sub-regions (e.g., the Gulf of Maine, New England). Datasets that are national in scope or are relevant to three or more of the NER parks are described here and not included under individual park summaries. These datasets should be incorporated as part of any park-specific analyses. A full assessment of the datasets available for a particular park will comprise local and/or park-specific data, as well as relevant national and regional datasets.

Bathymetry
Relevant to all 10 parks, the National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center's (NGDC) website provides access to national and international bathymetry data from a multitude of sources, collected with a variety of mapping tools (NOAA NGDC 2012). Examples include hydrographic survey, multibeam, trackline, and satellite-derived bathymetry data, as well as combined bathymetry and topography products. This portal represents a primary resource for accessing bathymetric data relevant to the NER parks.

The NOAA NGDC website features 3-arc-second (about 90 m) coastal relief models for the U.S. North East and South East Atlantic Coast1 (NOAA NGDC 1999 a, b; 2011; 2012). These relief models provide a continuous and seamless representation of the East Coast coastal zone from land to offshore with elevations resolved to 0.1 m (Figure 1). These models integrate USGS 3-arc-second DEMs with hydrographic soundings, multibeam bathymetry, and trackline bathymetry collected by NOAA National Ocean Service and various academic institutions. Data sources include the NOS hydrographic sounding CD-ROM, the NOAA NGDC multibeam database, digitized NOS soundings, USGS DEMs, and other sources. The database includes grids detailing the number of soundings enclosed by each cell, as well as elevation and sounding density images. A disclaimer provided with the models explains that the data are of high quality and useful for planning and modeling purposes, but they "do not necessarily reflect current conditions, nor do they depict data which is on a nautical chart."

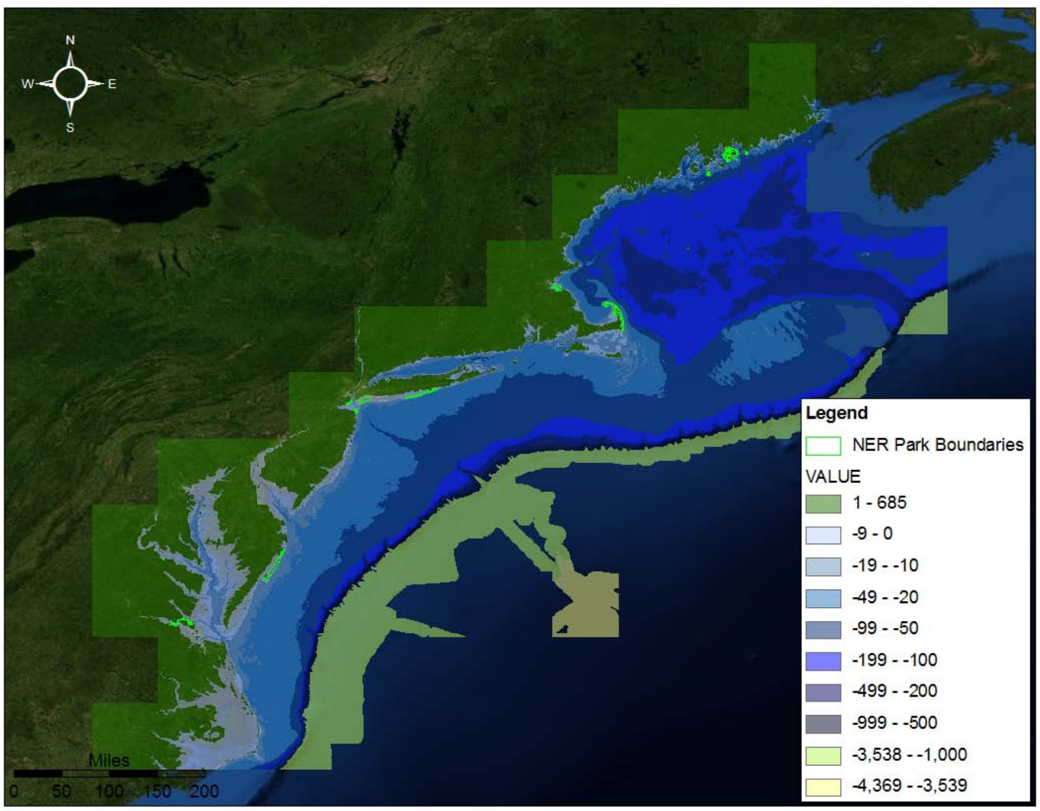

Figure 1. NOAA National Geophysical Data Center National 90-m Bathymetry Digital Elevation Model (NOAA NGDC 1999a, b) overlaid with NER park boundaries.

Also available from NOAA NGDC are digital raster compilations of NOS hydrographic soundings data from the 1840s through 1998 for select U.S. estuaries[234] (NOAA 2007). A number of the featured estuaries abut or overlap U.S. NER parks. The estuarine bathymetry map for Bar Harbor is relevant to ACAD, Cape Cod Bay (CACO), Massachusetts Bay (BOHA), Chesapeake Bay, VA/MD (COLO and GEWA), Great South Bay (FIIS), Long Island Sound (SAHI), and Raritan Bay (GATE). Products available for each estuary include 30-m and 3-arc-second DEM bathymetry datasets, sounding capture images, metadata, and supporting information. These compilations include interpolations of individual point source soundings from surveys spanning over a century.

Several regional bathymetry products are available to NER parks. A 15-second grid of the Gulf of Maine was produced by the Massachusetts Office of Geographic Information (MassGIS 1999) using bathymetric vector contour coverage available through the USGS Coastal and Marine Geology Program[222] (Roworth and Signell 1998). The datalayer represents seafloor topography extending from the Bay of Fundy to the Continental Shelf southeast of Nantucket and incorporates ACAD, BOHA, CACO, and SAIR (Figure 2). To compile the contours, USGS collected data from seven datasets including: (1) NOAA Hydrographic Survey and NOAA NGDC Marine Trackline Geophysics Data surveys from as early as 1930 (greater than 0.5-km resolution); (2) the Naval Oceanographic Office; (3) Bedford Institute of Oceanography and Brookhaven National Laboratory; (4) NOAA digital shoreline and U.S. Defense Mapping Agency (DMA) World Vector Shoreline Data; (5) DMA ETOP05 Digital relief of land and seafloor elevations (5-min grid); (6) General Bathymetric Chart of the Oceans (GEBCO) (1:10 million to 1:500,000); and (7) USGS 30-arc-second DEMs.

Incorporating ACAD, BOHA, CACO, and SAIR, a 1:24,000 bathymetry grid for the U.S. Gulf of Maine was developed by the U.S. Fish and Wildlife Service (USFWS) Gulf of Maine Coastal Program to assist characterization of inshore and wetland habitats[220] (Figure 3; Banner 2002). Sounding data from deeper areas were used to generate a coarse-resolution bathymetry grid. Data sources for the bathymetry grid included the USGS Gulf of Maine 500-m (15-second) grid (Figure 4; MassGIS 1999; Roworth and Signell 1998), NOAA NGDC bathymetry soundings on cd-rom, NOAA 30-m bathymetric grids, and nautical charts. Finer spatial resolution around inshore features was achieved using tidal exposure classifications described from aerial photography, maps of channels and tidal flats derived from Maine’s Coastal Marine Geologic Environments photography, and state orthophoto wetlands maps. The inshore classifications were coded according to their position within the intertidal zone, but not translated into absolute elevations.

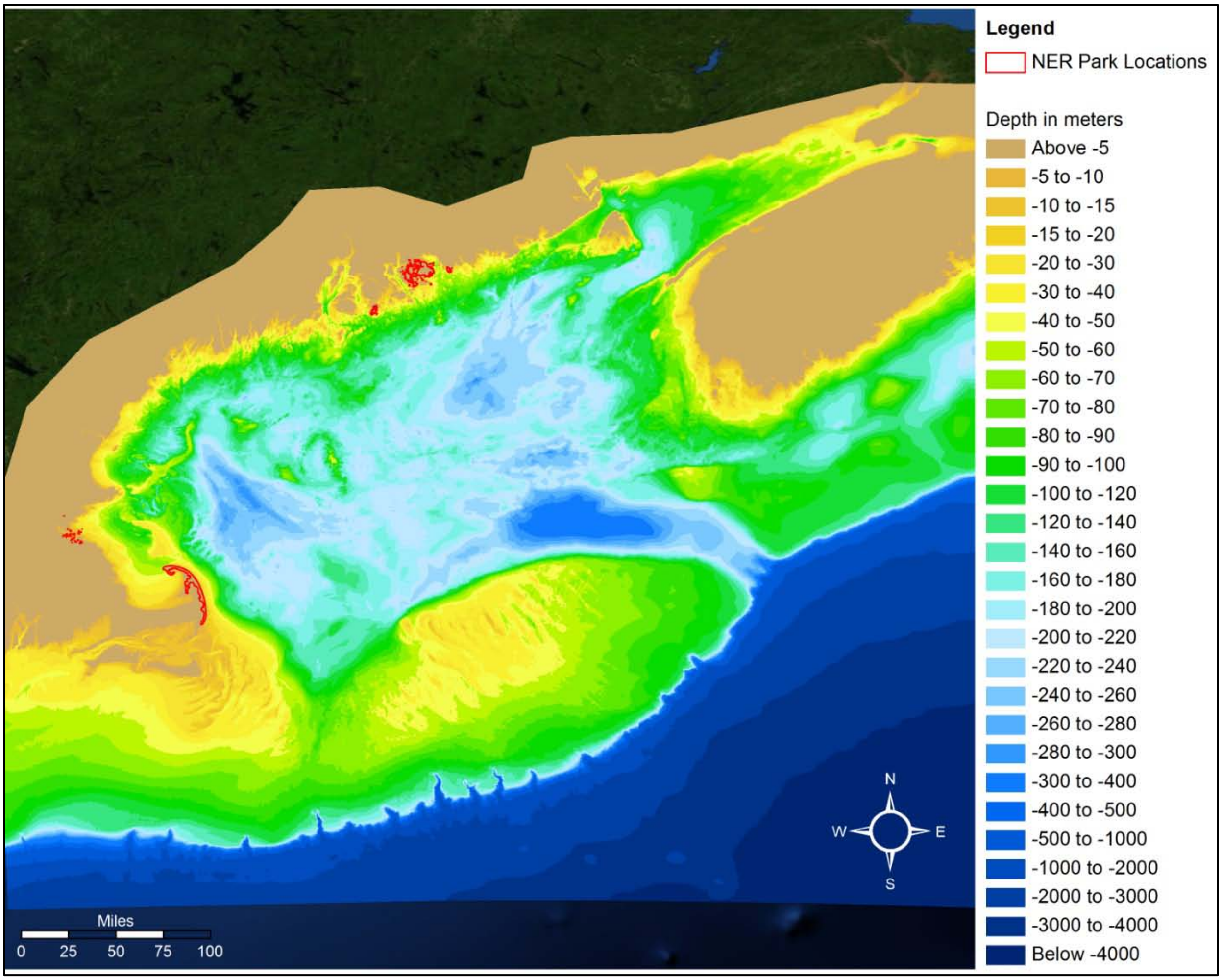

Figure 2. 15-second bathymetric contour coverage of the Gulf of Maine. Massachusetts Office of Geographic Information Systems (MassGIS 1999).

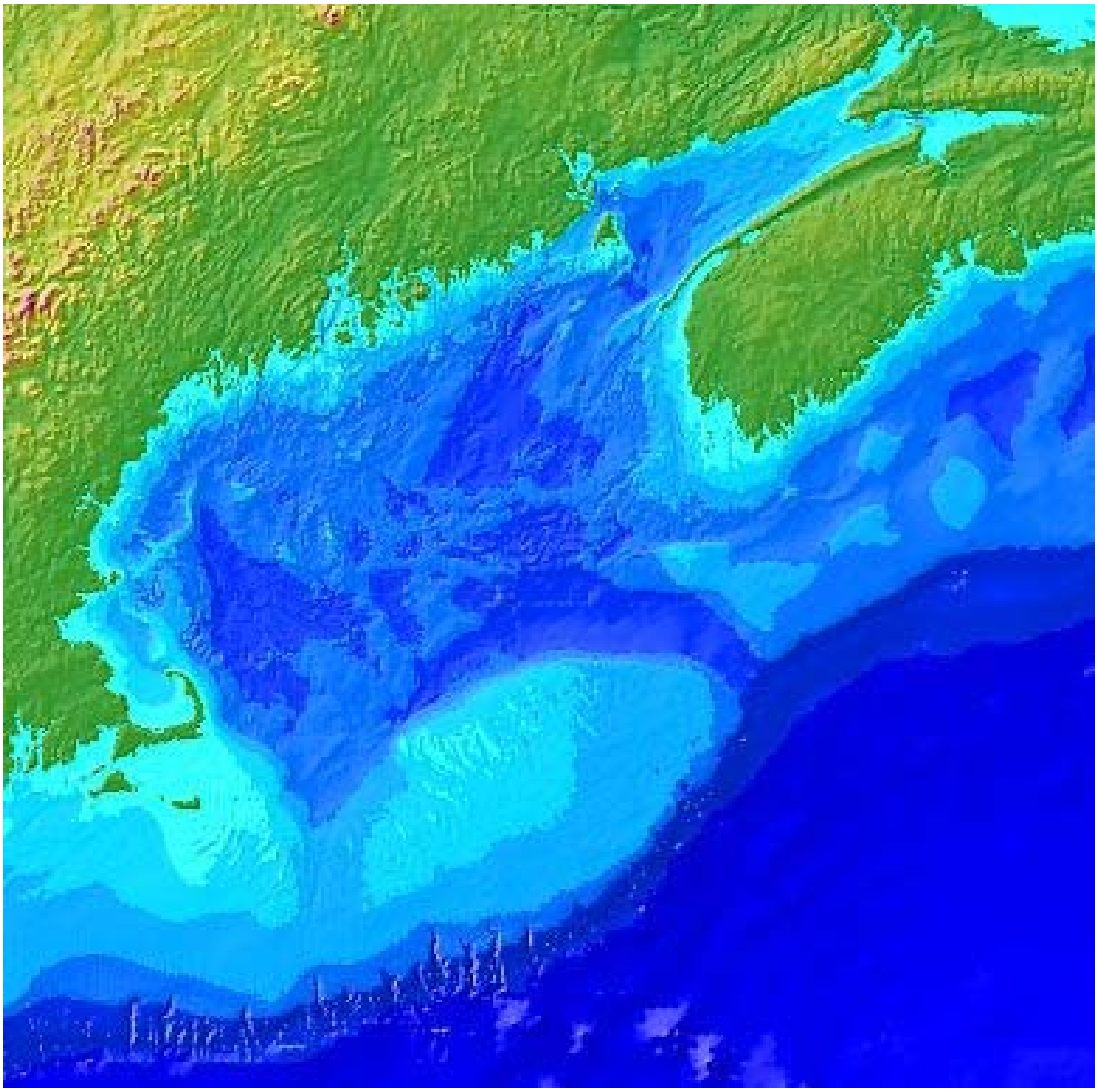

Figure 3. 1:24,000 bathymetry grid for the U.S. Gulf of Maine by the U.S. Fish and Wildlife Service Gulf of Maine Coastal Program (Banner 2002).

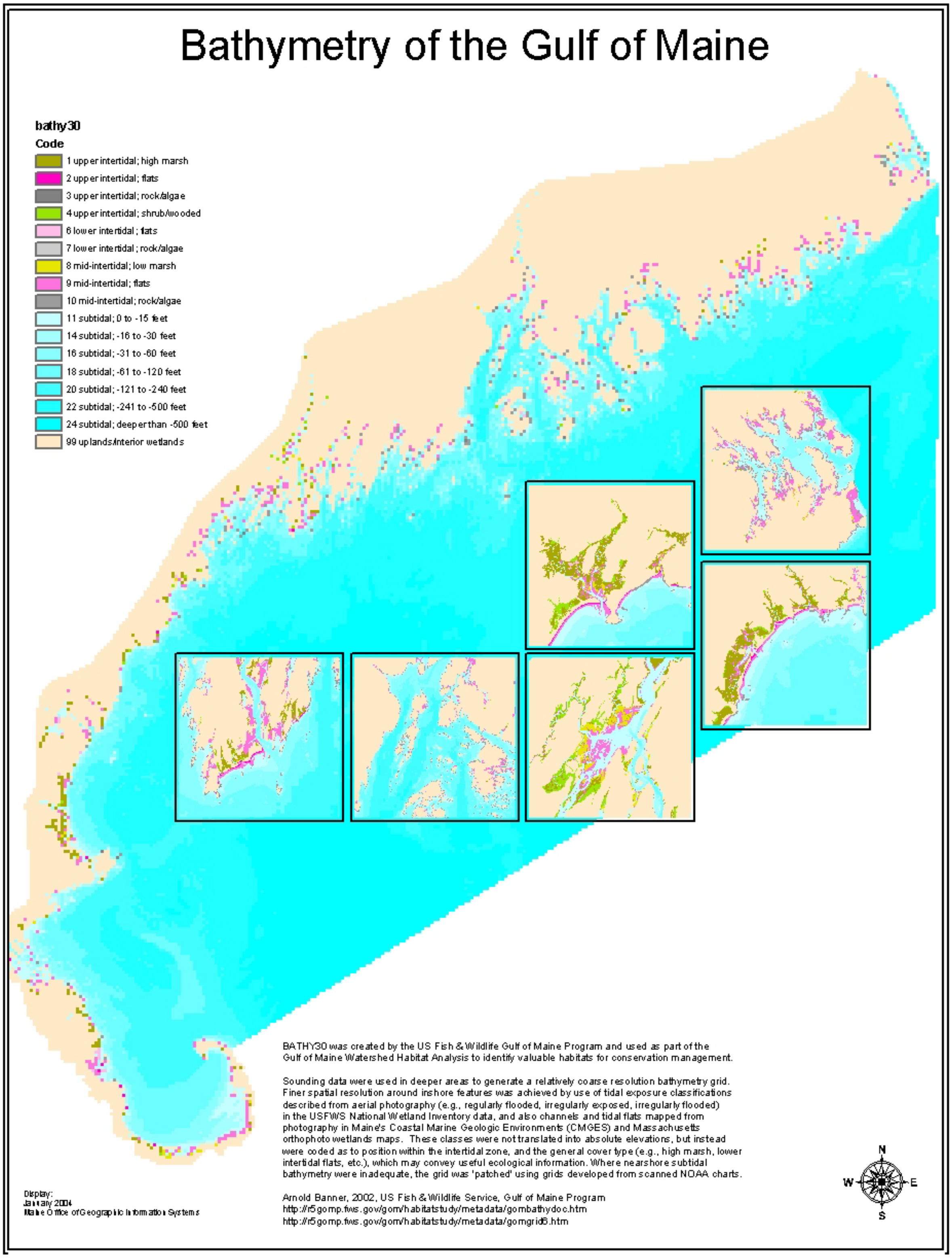

Figure 4. Digital bathymetry for the Gulf of Maine. U.S. Geological Survey Open-File Report (Roworth and Signell 1998).

Relevant to GATE, FIIS, and ASIS, the NOAA Coastal Services Center published coastal topographic and bathymetric lidar survey data collected along the New York, New Jersey, Maryland, and Virginia coastline as part of the National Coastal Mapping Program (NOAA CSC 2006). The data were collected in 2005 by the Joint Airborne Lidar Bathymetry Technical Center of eXpertise (JALBTCX) for the U.S. Army Corps of Engineers. Similarly, pertaining to CACO, BOHA, and ACAD, the NOAA Coastal Services Center published coastal topographic and bathymetric lidar survey data for Maine, Massachusetts, and Rhode Island, collected in 2007, also by JALBTCX (NOAA CSC 2009). For both datasets, SHOALS-1000T hydrographic laser instrumentation operated at a 1-kHz sampling rate, with 5-m by 5-m spot spacing, and an average 2-m spacing between postings. The surveys mapped topographic elevations extending 750 m inland from the shoreline along the states' coastal zones. The data were collected to achieve a horizontal accuracy of 0.75 m at 1 sigma and vertical accuracy of 0.20 m at 1 sigma. Measurements of bathymetric elevations out to 1500 m from shore were achievable where depth and clarity allowed; however, Flood et al. (2008) note that the lidar surveys "apparently failed to map water depths even in relatively shallow water due to turbidity in the water" (p. 4) and Dr. Kirk Waters, Coastal Remote Sensing Program Manager with NOAA Coastal Services Center, confirmed that the turbidity was likely too high to record bathymetric elevations during the surveys (email communication, 12-2-2011). The survey footprint and metadata can be viewed on the NOAA CSC Digital Coast Data Access Viewer (NOAA CSC 2012).

Hydrography

Wave height, direction, and periodicity

The Environmental Modeling Center, within the NOAA National Weather Service (NWS), maintains and operates an ocean wave model (WAVEWATCH III®) to forecast wind speed and direction and wave height, period, and direction at global and regional scales[11]. An online product viewer displays forecast maps of user-selected parameters within broad regions of interest (NOAA NWS 2012a). Forecasts are provided for 3-hour intervals from the model start time to 180 hours into the future. The U.S. East Coast product-viewer provides wave forecasts on a regional scale encompassing all NER parks. Wave model predictions are validated with wave height data from open-ocean buoys and satellites (Tolman 2002). Real-time data are transmitted from moored buoys in coastal waters maintained by the National Data Buoy Center (NDBC) within the NOAA National Weather Service[12] (NOAA NWS 2012b). Meteorological and oceanographic sensors are installed on the NDBC buoys to measure wave, wind, and atmospheric conditions at specific locations. In addition, a variety of regional and local programs also maintain oceanographic data buoys in northeastern coastal waters. The Regional Coastal Observing Systems provide "one-stop shopping" real-time portals to these various sources of data; those relevant to NER parks are the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS; NERACOOS 2012) and the Mid-Atlantic Regional Association of Coastal and Ocean Observing (MARACOOS; MARACOOS 2012). The locations of buoys in the vicinity of NER parks are identified in the park-specific data descriptions.

Tide range, phase, and currents

The Center for Operational Oceanographic Products and Services (CO-OPS), within NOAA National Ocean Service, provides the national infrastructure, science, and technical expertise to monitor, assess, and distribute tide, current, and water-level data (NOAA NOS 2011). The NOS National Water Level Observation Network (NWLON) is a network of long-term, continuously operating water-level stations throughout the U.S. that provide reference data for tidal predictions. The predicted time and height of daily high and low tides are computed by CO-OPS for more than 3000 stations around the U.S. shoreline (NOAA 2011a). Daily tidal current predictions are also available in various bays, harbors, estuaries, rivers, and channels coastwide (NOAA 2011b). Through the NOS Physical Oceanographic Real-Time System (PORTS), real-time observations and predictions of water levels, currents, salinity, and meteorological parameters for 15 major U.S. harbors are integrated and delivered (NOAA NOS 2011). As most harbors are located at the mouths of major estuaries, there are several PORTS stations near NER parks. NOS and other monitoring stations providing real-time tide data are compiled and provided through the NERACOOS and MARACOOS portals. The locations of tide monitoring stations in the vicinity of NER parks are identified in the park-specific data descriptions. USGS National Water Information System (NWIS) also maintains water-level recording stations throughout each state, a small proportion of which are estuarine and ocean stations (USGS 2012b). The locations of NOAA and USGS water-level monitoring stations in the vicinity of NER parks are identified in the park-specific data descriptions.

Estuarine monitoring implemented within the NPS NCBN Vital Signs Monitoring Program includes continuous water-level recording at a representative location within many important NCBN park estuaries (CACO, GATE, FIIS, GEWA, ASIS, COLO). Estuarine monitoring in each park is implemented at least every other year following a Vital Signs protocol (Kopp and Neckles 2009). Generally, one continuous monitoring station is established within each park during a four-week, mid-summer index period. Continuous water-level data during the summer index period are archived with the NPS Northeast Coastal Barrier Network Data Management Program (NPS 2010).

Hydrogeologic Framework

Bedrock geology and shallow stratigraphy

The NPS Geologic Resources Inventory (GRI) was begun in 1998 to enhance baseline geologic information available to park managers at each of 270 natural area parks nationwide (NPS 2012a). The inventory for each park is initiated with a geologic scoping meeting to identify geologic mapping coverage and needs. These meetings provide a forum for evaluating the adequacy of existing geologic maps for resource management. The Scoping Reports summarize existing geologic data sources and identify needs for additional data to meet park-specific geologic resource management issues. The GRI program then provides the park with a digital geologic map and accompanying data layers, and a geologic report to serve as a cross-link between the digital geologic map and each park's geologic features, process, history, and geology-related resource management issues. Geologic reports also include a map unit properties table highlighting properties of each geologic unit on the map. Geologic data prepared as part of the GRI program can be downloaded in GIS format from the NPS Integrated Resource Management Applications (IRMA) Portal web site (NPS 2012b). The current status of GRI products is identified in Table 4.

Surface and groundwater pathways

The United States Geological Survey (USGS) collects water-resources data at approximately 1.5 million sites throughout the US states and territories. Data on surface-water level and stream flow (discharge) are collected at major rivers, lakes, and reservoirs, and data on groundwater level are collected at wells and springs. Current and historical data are available online through the NWIS web interface (USGS 2012b). Locations of USGS monitoring stations in the vicinity of NER parks are identified within descriptions of park-specific hydrography data.

Buxton and Smolensky (1999) simulated the effects of development on the ground-water flow system of Long Island, providing information pertinent to GATE, FIIS, and SAHI. The report describes ground-water levels, stream-flow, aquifer locations and characteristics, recharge and discharge areas, changes in the ground-water budget, and the estimated effects of a proposed 2020 water supply strategy. The study evaluates the sensitivity of stream base flow to water-table fluctuations, the effects of development scenarios, and opportunities to reduce the threat of salt water intrusion from groundwater withdrawals.

Table 4. Status of Geologic Resources Inventories for NER coastal parks as of April 2012 from the GRI online database (NPS 2012a).

Park	Scoping Report Date	Digital Geologic Map Status	Geologic Report Status
GATE	2011	In progress (2013)	Awaiting map (2017)
CACO	2008	Completed 2010	In progress (2014)
ASIS	2005	Completed 2009	Krantz 2010
FIIS	2011	In progress (2013)	Awaiting map (2017)
BOHA	2008	In progress (2012)	Awaiting map (2015)
ACAD	2008	Completed 2006	Graham 2010
COLO	2005	Completed 2011 (NPS Access Only)	Awaiting map (2015)
GEWA	2005	Completed 2006	Thornberry-Erlich 2009 In progress (2017)
SAHI	2011	Completed 2010	Thornberry-Erlich 2009 In progress (2017)
SAIR	2008	Completed 2011	Awaiting map (2016)

Surficial Geology

Acoustic seabed characterization

From 2002 to 2010, the USGS National Benthic Habitat Studies Project for the Atlantic region conducted research and classification of seabed habitats with consideration of seabed processes, geologic framework, and function as substrate for marine species (Valentine et al. 2009). Objectives for the Atlantic project included habitat classification and process studies of New England benthic habitats, and geologic and biological studies in areas including the Gulf of Maine and Mid-Atlantic region. The studies utilized high-resolution seafloor bathymetry, backscatter data, groundtruth data (video, photo imagery, and geological and biological samples), and information about bottom characteristics and sediment distribution contained in the usSEABED database (see *National and Regional Datasets—Sediment grain size and organic content*). These datasets were used to produce interpretive maps of surficial and subsurface geology, classified habitats, distribution of fauna and flora, and effects of seabed processes. Publications resulting from this project provide acoustic seabed characterization relevant to the most northern extent of CACO (Valentine et al. 2003; see CACO *Acoustic Seabed Characterization*).

Sediment grain size and organic content

The U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP) was a research program run by EPA's Office of Research and Development to develop the tools necessary to monitor and assess the status and trends of national ecological resources. EMAP's National Coastal Assessment (NCA) comprises all the estuarine and coastal sampling done by EMAP beginning in 1990 (EPA 2010b), including early development from 1990 to 1993[194] in the Virginian biogeographic province (Cape Cod, Massachusetts to the mouth of Chesapeake Bay, Virginia, relevant to CACO, GATE, FIIS, SAHI, GEWA, ASIS, COLO); a Mid-Atlantic Integrated Assessment from 1997 to 1998[195] (relevant to GEWA, ASIS, COLO); regional studies in New York/New Jersey Harbor in 1993-1994 and 1998[199, 200] (relevant to GATE); and annual NCA sampling in northeastern coastal waters from 2000 to 2006[191, 192, 196] (relevant to all NER coastal parks). NCA used a probabilistic sampling design to survey a common set of environmental indicators in all coastal states in the country (Strobel and Heitmuller 2001). Indicators included sediment grain size (percent sand, percent silt/clay) and organic-content attributes (percent total organic carbon (TOC). The goal of NCA was to generate regional characterizations of the Nation's coastal resources; consequently, sampling stations were distributed throughout the entire coastal zone at a sampling density sufficient to draw regional inferences. Each state was allocated at least 35 randomly selected sampling stations (EPA 2001). Although only a small proportion of sampling stations in the northeastern states fell within park boundaries proper, the NCA data do provide a broad regional context for sediment conditions within the parks. Sampling stations can be viewed using an online mapping application and all NCA datasets can be downloaded directly (EPA 2010a). Data on sediment TOC have been combined with data on sediment toxicity and sediment contaminants into a sediment condition index, which is summarized in three reports on coastal condition (EPA 2005, EPA 2008, EPA 2012a). Since 2010, EPA monitoring of coastal resources, including sediment attributes, has been conducted at five-year intervals by the National Aquatic Resource Survey (NARS) run by EPA's Office of Water (EPA 2012c). Regional data collected by the NCA and NARS programs are also relevant to other NER priority data needs (see *National and Regional Datasets – Submerged habitats and biological communities; Sediment contaminants; and Water chemistry and water quality*).

A series of geological digital databases and 1:1,000,000 scale maps for the continental margin of the U.S. Atlantic coast is available through the Atlantic Continental Margin Mapping Project (CONMAP), a joint marine geology program of USGS and Woods Hole Oceanographic Institution (WHOI)[27] (USGS 2000; USGS 2005; Poppe et al. 2005a). The sediment map within the CONMAP series (Polloni et al. 2005) is a compilation of grain size data produced by USGS and other entities. CONMAP data consist of a compilation of ~3800 surficial sediment samples collected from 1962 to 1970 and classified using the Wentworth (1922) grain size scale and the Shepard (1954) scheme of sediment classification. The metadata cautions that "the CONMAP series is old and does not accurately depict small-scale sediment distributions. This data layer is supplied primarily as a gross overview and to show general textural trends" (USGS 2005).

The East Coast Sediment Texture Database was developed to gather all available grain size data produced by the USGS Woods Hole Science Center into a scientifically-edited database[28, 30] (Hastings et al. 2005; McMullen et al. 2005). The original 2005 database contained grain size data from over 23,000 sediment samples collected along the East Coast. Approximately 19,500 of these samples were collected from 1980 to 1999 and analyzed by USGS. Another ~3800 samples were collected from 1962 to 1970 as part of CONMAP (described previously). Data from 1970 to 1980 were yet to be digitized and added to the database when the database was published. A 2011 update of the database includes data spanning from 1955 to 2011 totaling over 26,000 sediment samples (USGS 2011). Sediment classification maps of these data are available for the entire Atlantic Coastal Margin, as well as for selected regions including the Gulf of Maine and Mid-Atlantic/NY Bight (Figure 5). GIS analysis indicates that only a limited number of samples in the databases were taken within or abutting NER park boundaries (i.e., one sample at ASIS, two at GATE, about 15 at BOHA, five at CACO and FIIS, a small number at ACAD, and none at GEWA, COLO, SAHI, and SAIR). However, sediment classifications have been interpolated to cover larger areas of the parks. Interpolated sediment classifications cover all of the sub-tidal area of CACO, ASIS, FIIS, and BOHA, parts of GEWA, COLO, and ACAD, most of the Sandy Hook and Raritan Bay sections of GATE, and a small section of GATE at the entrance to Jamaica Bay.

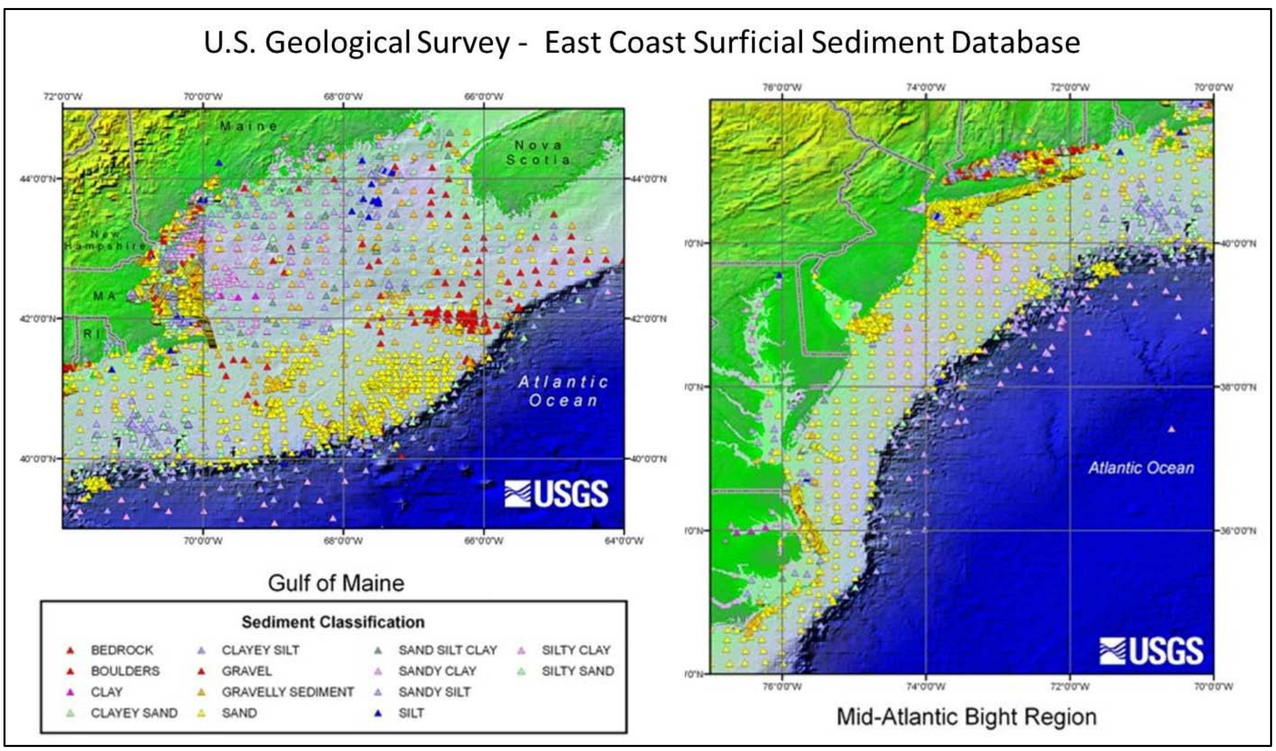

Figure 5. East Coast Sediment Texture Database visualization maps for the Gulf of Maine and Mid-Atlantic Bight Region. Open-file report 2005-1001, U.S. Geological Survey Coastal and Marine Geology Program, Woods Hole, Massachusetts.

In 2005, USGS published the first release of Atlantic coast data from the usSEABED database (Reid et al. 2005). This dataset is part of a nationwide effort to gather marine geologic data for use in assessments of offshore sand and gravel resources and for producing GIS map products of seafloor geology. The data represent published and unpublished sediment texture and character data from a wide variety of sources compiled by USGS and other federal, state, and university partners. The database includes usSEABED data, maps, and a data catalog. The maps display sediment grain size and lithology; seabed attributes such as sediment texture, composition, color, ripples and biota; seafloor hardness; acoustic properties; and geochemical and geotechnical properties. The full list of usSEABED data themes currently includes descriptors of geological materials and structures (lithology), grain type by abundance (petrologic grain counts), color, texture/particle size, acoustic properties, sediment density and strength characteristics (geotechnics), composition, geochemistry, turbidity, related oceanographic parameters, sediment mobility and erodibility (hydrodynamics), seafloor type, biological colonization, coastal geomorphology, and sediment thickness (Williams et al. 2003).

The USGS Marine Aggregate Resources Project (MARP) consists of rigorous regional assessments of marine and gravel resources and seafloor sedimentary character (Williams et al. 2003; USGS 2009a). The MARP study uses usSEABED data to map benthic habitats and seafloor properties and assess potential sand sources. MARP was developed to meet the need for a unified database of marine sediments and a digital geologic map series of seafloor texture and character. Collaborators include USGS, the Office of Naval Research, Minerals Management Service, the U.S. Army Corps of Engineers (USACOE), NOAA, coastal states, and universities. Regional assessments pertaining to the NER coastal parks include the New York Bight region (see GATE *Sediment grain size and organic content*) and Gulf of Maine (Poppe et al. 2003; see *BOHA, CACO, and ACAD—Sediment grain size and organic content*). The Gulf of Maine regional assessment includes 42 sediment data layers of surficial sediment distributions in the Gulf of Maine and vicinity compiled by USGS in cooperation with the University of Maine, University of New Hampshire, Boston University, and Bigelow Laboratory for Ocean Sciences. The Gulf of Maine surficial sediment data compilation contains grain size and lithology information from over 47,000 sampling stations.

Sediment Contaminants

From 1990 to 2006, EPA’s National Coastal Assessment (NCA) collected data on the ecological and environmental conditions in U.S. coastal waters (see full description of years and locations of data collection in *National and Regional Datasets–Sediment grain size and organic content*; EPA 2001, Strobel and Heitmuller 2001). Since 2010, the National Aquatic Resource Survey (NARS) has conducted monitoring of coastal resources at five-year intervals using NCA protocols (EPA 2012c). Sediment contaminants sampled by both programs include a long list of organic compounds (polynuclear aromatic hydrocarbons, DDT and its metabolites, and chlorinated pesticides other than DDT) and trace elements (e.g., aluminum, cadmium, chromium, copper, lead, mercury, tin, zinc; EPA 2001). In addition, surfical sediment was collected for acute toxicity testing (exposure of marine amphipods to test treatments under static conditions; EPA 2001). Sampling stations can be viewed at an online mapping application and all NCA datasets can be downloaded directly (EPA 2010a). Only a small number of sampling stations fall within NER park boundaries. Data on sediment toxicity and sediment contaminants have been combined with data on sediment TOC (see *National and Regional Datasets–Sediment grain size* *and organic content)* into a sediment condition index, which is summarized in three reports on coastal condition (EPA 2005, 2008, 2012a).

Water Chemistry and Water Quality

In addition to data on sediments, the EPA's National Coastal Assessment (NCA) and National Aquatic Resource Survey (NARS) also collected data on water chemistry and water quality in U.S. coastal waters collectively from 1990 to the present (see full description of years and locations of data collection in *National and Regional Datasets–Sediment grain size and organic content*; EPA 2001, Strobel and Heitmuller 2001, EPA 2012c). Water-chemistry and water-quality variables sampled by both programs include dissolved oxygen, pH, salinity, temperature, light attenuation, chlorophyll a, total suspended sediments, and dissolved nitrogen and phosphorus species; data have been summarized in three reports on coastal condition (EPA 2005, 2008, 2012a). Only a small proportion of the sampling stations fall within park boundaries.

The U.S. EPA STORET (STOrage and RETrieval) Data Warehouse is a repository for water quality monitoring data. Data are entered to STORET by a variety of groups, including federalagencies, states, tribes, local governments, academic groups, watershed and volunteer monitoring organizations, and the public. Data available for individual locations can be downloaded from the EPA STORET database directly (EPA 2012b) or in conjunction with water-quality data in the USGS National Water Information System (NWIS) from the Water Quality Portal (NWQMC 2012). Some datasets were downloaded from STORET and incorporated into the Inventory for this project *(*see GATE and FIIS -*Sediment contaminants* and *Water chemistry and water quality).* The NPS Inventory and Monitoring Program and the NPS Water Resources Division partnered to prepare Baseline Water Quality Data Inventory and Analysis Reports for Network parks[83, 101]. These reports inventory and describe available water-quality data that exist in STORET and NWIS. Baseline Water Quality Data reports were produced for NER parks as follows: ACAD, COLO - 1994; ASIS, CACO - 1995; GATE, GEWA - 1997, SAHI - 1998. Reports are available from NPS (2012c).

The U.S. Clean Water Act (CWA) regulates quality standards for surface waters of the United States. CWA Section 305(b) requires states to use monitoring data and other information to report bi-annually the status of their waters, including estuaries; assessed waters are classified as either Fully Supporting, Threatened, or Not Supporting their designated uses. CWA Section 303(d) requires states to use monitoring data and other information to develop a list of waters that will not meet water quality standards for a particular pollutant; states must then develop Total Maximum Daily Loads to restore these waters. Biennially, states submit an Integrated Report summarizing the status of their assessed waters (as required under section 305(b)), a listing of impaired waters and the causes of impairment, and the status of actions being taken to restore impaired waters (as required under section 303(d)). These reports and available data can be retrieved for specific water bodies from EPA (2012d). Examples of state assessment data and reports relevant to several parks are included in the inventory (COLO and GEWA[89]; FIIS, SAHI, and GATE-Jamaica Bay, Staten Island[96]; GATE-Sandy Hook[97, 99]).

Estuarine monitoring is conducted in parks of the NPS Northeast Coastal and Barrier Network (NCBN) through the network's Vital Signs Monitoring program (Kopp and Neckles 2009). Monitoring of water chemistry and water quality was initiated in some NCBN estuaries in 2003 during protocol development phases. Full implementation began on a rotating basis in 2008;

estuarine monitoring is conducted at least every other year in each of six NCBN parks containing significant aquatic resources: CACO, GATE, FIIS, ASIS, GEWA, and COLO (Table 5). Indicators of estuarine response to nutrient enrichment (dissolved oxygen, chlorophyll concentration, turbidity, and light attenuation) and ancillary explanatory variables (temperature and salinity) are monitored during a four-week summer index period at a hierarchy of spatial and temporal scales. At each park, the spatial framework for monitoring encompasses all of the estuarine area falling within the park boundary; if practicable, this framework is expanded to include estuarine area outside the park boundary that is integrally connected to park waters. Within each park, a spatial survey is conducted once during the index period following a probability design that uses a grid of tessellated hexagons as the basis for random sample-site selection. To improve trend detection, this spatial survey is supplemented with weekly measurements at a subset of the probability sites and continuous monitoring at a single reference site. Evaluation of park-specific data permits determination of the mean condition of park estuaries, the percent of the estuarine area exceeding threshold values, trends in estuarine condition over different time scales, and the likelihood that nutrient enrichment is a primary stressor on park ecosystems. Kopp et al. (2009) summarized data collected between 2003 and 2006, and data collected between 2006 and 2011 are currently being summarized by Hilary Neckles (USGS Patuxent Wildlife Research Center) and James Caldwell (USGS Maine Water Science Center).

Table 5. Years in which estuarine water-quality monitoring has occurred in specific NCBN parks (identified by X).

	Year								
Park	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Cape Cod NS					X	X	X	X	X
Fire Island NS	X						X		X
Gateway NRA	X		X	X					
Assateague Island NS			X	X		X		X	
George Washington Birthplace NM							X		X
Colonial NHP	X					X		X	

Two regional projects collect salinity and temperature data on a coarse spatial scale. First, the NOAA Northeast Fisheries Science Center collects salinity and surface and bottom temperature data during surveys of the northeast continental shelf from Maine to North Carolina[77] (NOAA NEFSC 2012a). Second, the eMOLT (Environmental Monitors on Lobster Traps) project is a non-profit collaboration of industry, science, and academics devoted to monitoring the physical environment of the Gulf of Maine and the Southern New England shelf[78] (NOAA NEFSC 2012b). Since 2001, temperature loggers have been attached to lobster traps to monitor bottom temperature in coastal waters from Maine to Massachusetts and by 2006 there were 115 eMOLT temperature-monitoring sites spanning multiple years. In 2012 the database included 5 million hourly records of temperature and 80 thousand hourly records of salinity. Although sampling locations for the continental shelf surveys and the eMOLT lobster traps are offshore of park estuaries, the data provide broad regional context for conditions in park estuaries and a long-term record of water parameters that are associated with global climate change.

Submerged Habitats and Biological Communities

Seagrass distribution

Data on seagrass distribution in the northeastern and mid-Atlantic regions of the United States were compiled within a global atlas of seagrasses in 2003 (Short and Short 2003, Koch and Orth 2003). The global database was updated in 2005; point and polygon data can be viewed using online mapping tools or downloaded (UNEP-WCMC 2005).

Biological communities and species inventories

The USFWS National Wetlands Inventory (NWI) includes a series of topical maps of freshwater, estuarine, and marine wetlands throughout the U.S.[102] (USFWS 2011). Information available for download on the NWI website includes digital maps, geospatial digital data, wetland classification codes, product summaries, and metadata. Maps are based on interpretation of aerial photography, soil surveys, and field checks of wetland photo signatures. Delineated wetland boundaries are transferred from interpreted aerial photos onto USGS 7.5-minute topographic quadrangle maps. The project inventories and classifies all wetlands contained within the 10 parks. Several regional and park-specific products have been produced through this program (see *Benthic Communities and Species Inventories* for each park).

The NOAA Northeast Fisheries Science Center (NEFSC) Bottom Trawl Survey Data contains 460,938 records pertaining to Northwest Atlantic fish and invertebrate species[103] (NOAA NEFSC 2009). Bottom trawl surveys are conducted in ocean (not bayside) environments extending from Cape Hatteras to Maine and from the coast to slope water. Data collected from trawls include weight, length, total catch numbers, age, maturity, sex, and food content. Plankton data are collected at a subset of stations. A survey description is available online (NOAA NEFSC 2011). Trawl records can be viewed in an online map viewer, or downloaded as a text, html, or KML file and include composition, distribution, and abundance information, as well as associated physical data (e.g., salinity, conductivity, and temperature). Because the trawls begin at the 30 ft depth contour, most trawl records do not overlap with park boundaries.

Environmental Sensitivity Index (ESI) atlases have been compiled for U.S. shorelines by the NOAA Office of Response and Restoration, and other federal, regional, state, and local agencies varying by location. The ESI atlases are collections of PDF maps and GIS data dating from 1984 to 2006 organized by state or groups of states (NOAA 2012). ESI maps contain information about the sensitivity of shoreline habitats, human-use areas, and biological resources to oil spill impacts. The classification of shorelines according to their oil-sensitivity involves assessment of factors such as relative exposure to wave and tidal energy, shoreline slope, substrate type and characteristics, biological productivity, and biological sensitivity. Review of existing maps, literature, and remote imagery is combined with observations from aerial surveys and ground observations. In most cases, the information is plotted on 7.5-minute 1:24,000 scale USGS quadrangles. Park units covered by the ESI include BOHA, CACO, GATE, GEWA, COLO, and the Virginia portion of ASIS. ESI atlases were developed to provide environmental data for oil spill planning and response.

In 1998, the NYS Department of State's Division of Coastal Resources identified the boundaries of Significant Coastal Fish and Wildlife Habitats in accordance with a state executive law, which requires the identification, assessment, and designation of these habitats under the NYS Coastal Management Program[157] (NYS 1998). The dataset consists of 250 sites statewide, including marine waters around NYC and Long Island Sound (GATE, SAHI, and FIIS). The data were hand-drawn on DOT topographic quadrangle sections. A heads-up digitizing process was used to create 1:24,000 scale digital maps of the identified habitats. For each designated site there is a habitat map and accompanying narrative with site-specific information about the habitat, the living resources that led to the area's designation, and an impact assessment. The maps are available online (NYS 2012a).

NOAA Fisheries works with the regional fishery management councils to identify the essential habitat for every life stage of federally managed species, and some of the essential fish habitat (EFH) designations include waters within park boundaries. A mapper for viewing important fish habitat in New England and mid-Atlantic coastal waters is available online (NOAA NMFS 2012). Supporting materials, including an EFH data inventory and fishery management plans, are also available.

Park-specific Datasets

Datasets included in this section pertain to individual parks or their local vicinity. Descriptions of datasets that encompass multiple parks or entire regions are described in the *National and Regional Datasets* section and are not repeated here.

Gateway National Recreation Area (GATE)

Bathymetry

National and regional datasets provide full bathymetric coverage of GATE at various resolutions; however, as of the inventory's completion date, high-resolution, continuous coverage bathymetric data were not available for all sub-tidal areas within the park. The following data descriptions represent the existing local and park-specific datasets available for GATE at the time of the inventory's completion, as well as a number of additional bathymetry datasets acquired post-inventory.

In addition to datasets described in the *National and regional Datasets—Bathymetry* section, the NOAA National Geophysical Data Center (NGDC) website houses localized bathymetry datasets for GATE in the form of 30-m and 3-arc-second DEMs, sounding capture images, and metadata for Raritan Bay (NOAA NGDC 2012; NOAA NOS 1998e). Developed as part of the U.S. Estuarine Bathymetry Project[234] (NOAA 2007), Raritan Bay bathymetry was compiled from 25 surveys conducted from 1927 to 1988 containing 230,575 soundings with an average separation of 13 m, as well as two additional surveys from 1950 and 1979 included after original publication (NOAA NOS 1998e). Seventeen 7.5-minute DEMs and two 1-degree DEMs were developed from the compiled data. The dataset covers the full Raritan Bay section of GATE, the full extent of Jamaica Bay proper, and the bayside section of Sandy Hook (Figure 6). The seaside portions of GATE outside of Jamaica Bay and Sandy Hook are not included within this dataset.

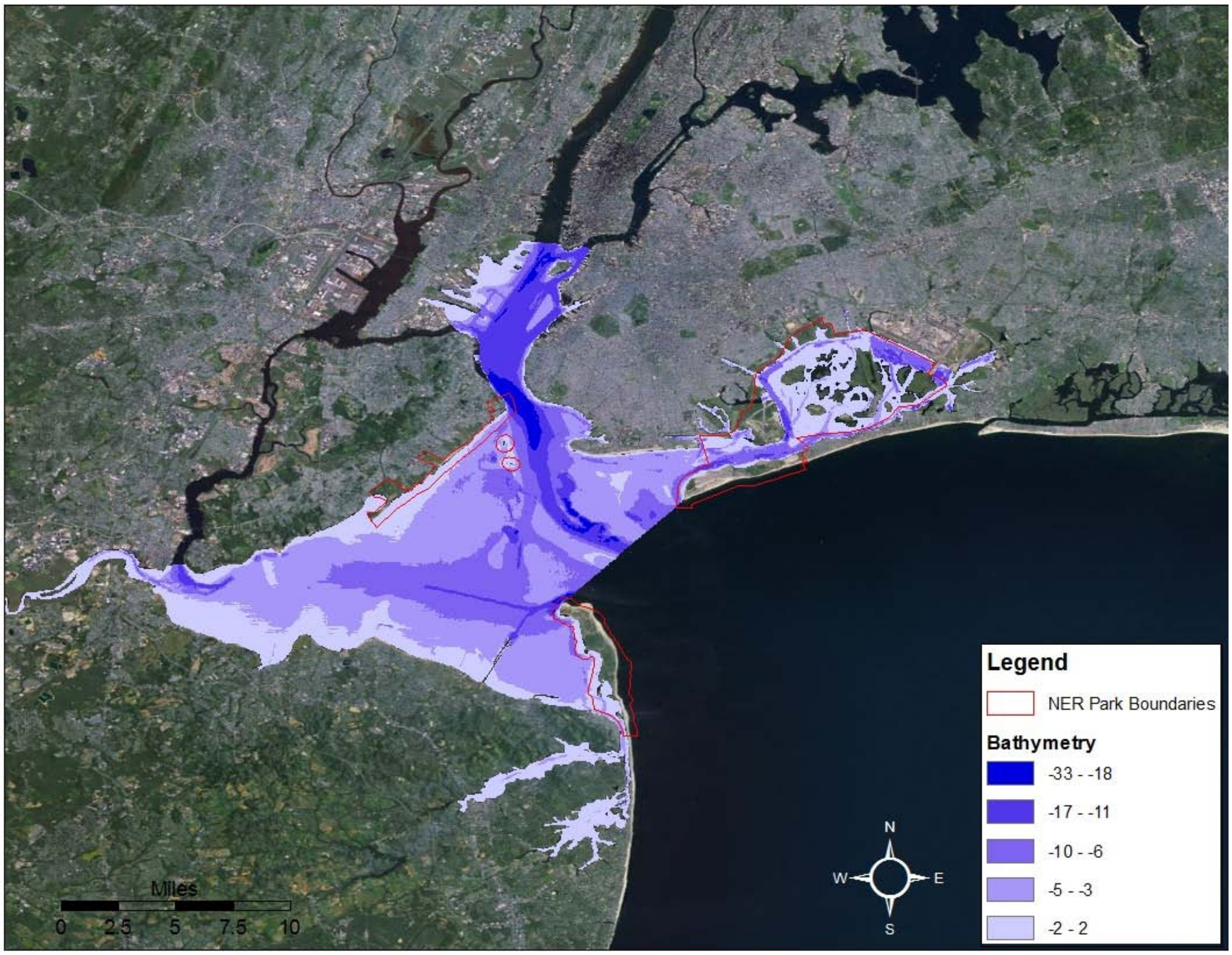

Figure 6. Bathymetric digital elevation model (30-m resolution) of Raritan Bay, derived from NOAA National Ocean Service hydrographic survey soundings (NOAA 2007; NOAA NOS 1998e), overlaid with Gateway National Recreation Area boundaries.

The Marine Sciences Research Center of the State University of New York (SUNY) at Stony Brook completed high-resolution bathymetry mapping and seabed classification in Jamaica Bay in 2008 and 2009[241] (see also GATE *Acoustic Seabed Characterization*). The data were not available for review at the time of this publication. The project proposal submitted by Flood et al. (2008) to NPS indicates that multibeam echosounders and sidescan sonar would be used to map deeper waters (greater than 2.5 m) with a minimum track spacing of 40 m. Single-beam echosounders would be used to map shallower areas (about 0.5 m to 2.5 m) with survey lines spaced 40 m apart and cross-lines spaced 200 m apart. Final GIS themes derived from acoustic surveys, discrete sampling, and interpretive processes are proposed to include the following: a 1-m grid multibeam bathymetry, sun-illuminated multibeam bathymetry, single-beam water depth point files, approximate 10-m grid single-beam bathymetry, 1-m grid multibeam backscatter, 1-m grid sidescan geotiff imagery, seabed classification benthic cover and geoform shapefiles, legacy bathymetry and backscatter data from 2000 and 2003 multibeam surveys, ancillary data, grain size sampling results, point files of penetrometer measurements of soil strength, and bottom images. Seabed classification will follow the CMECS approach and be based upon acoustic properties of the seabed as well as discrete sampling data. Once published, this dataset will presumably represent modern, high-resolution acoustic bathymetry data for all of Jamaica Bay deeper than 0.5 m (but not including the seaside portion of GATE's Jamaica Bay section).

Also pertaining to Jamaica Bay, CR Environmental, Inc. and Marine Search and Survey performed multibeam bathymetric surveys at two locations within Jamaica Bay (Little Bay and Norton Basin) in 2000 (CR Environmental, Inc. 2001). A seabed classification survey was also conducted as a part of this survey (see GATE—*Acoustic Seabed Characterization*). The project was performed to inform a proposed demonstration project by the U.S. Army Corps of Engineers (USACOE) focused on beneficial uses of dredged material. The surveyors operated a Reson 8101 multibeam system at 240 kHz, including a TSS Motion Sensor, SG Brown Gyro, the Trimble DGPS and the Coastal Oceanographics' Hypack Hysweep software map. Bathymetric data products included bathymetric maps and shaded relief maps of the survey areas.

In 2008, Rutgers University collected depths below the water surface and altitude above the bottom at the Kingman-Mills site within GATE's Sandy Hook section, as part of a survey of bottom and water column characteristics. Acoustic Doppler Current Profilers (ADCPs) mounted on a REMUS autonomous underwater vehicle (AUV) were used to survey the 1400-m by 250-m site[243] (Psuty and Silveira 2010). The elevation datasets were combined and analyzed to generate a bathymetric and underwater topography map of the study area. The datasets from the project include raw text files, shapefiles, density maps, raster files, and JPEG images, which are stored in a GIS database at GATE. The REMUS mapping was precipitated by plans to construct a ferry dock at the Sandy Hook Unit of GATE (Psuty et al. 2009); see also *GATE—Water quality* and *Acoustic seabed characterization*). This dataset represents recent, high-resolution bathymetry survey data for a very small area of the total GATE sub-tidal acreage.

The NOAA Coastal Services Center published coastal topographic and bathymetric lidar survey data collected along the New York, New Jersey, Maryland, and Virginia coastlines as part of the National Coastal Mapping Program (NOAA CSC 2006; see also *National and Regional Datasets—Bathymetry*). The survey foot print covers the shoreline and very nearshore areas for the majority of the Sandy Hook portion of GATE and a number of Jamaica Bay islands, as well small subtidal areas in the channel leading to Jamaica Bay.

Also notable are the products of a number of bathymetric surveys that occurred in the vicinity of GATE, but outside of park boundaries. An Internet Map Server (USGS 2008) and Project Pages (USGS 2009b) synthesize the USGS marine geologic data available for the New York Bight region. One-meter bathymetry contours for the New York Bight region were derived from five single-beam echosounder surveys conducted by USGS from 1995 to 1998 (Denny 2000), with a 300-m trackline spacing and data vertical accuracy of +/- 0.5 to 1 m (Figure 7). Multibeam swath bathymetry data were collected over the Hudson Shelf Valley area, significantly offshore and outside of park boundaries (Butman et al. 1998). This multibeam survey was nested within a sidescan-sonar and high-resolution geophysical survey of a larger area (Schwab et al. 2002; see also *GATE—Acoustic seabed characterization*). Additional sites were surveyed in 1996 and 1998 using a Simrad EM-1000 multibeam echo sounder (Schwab et al. 2000a), but these areas also do not directly fall within GATE park boundaries.

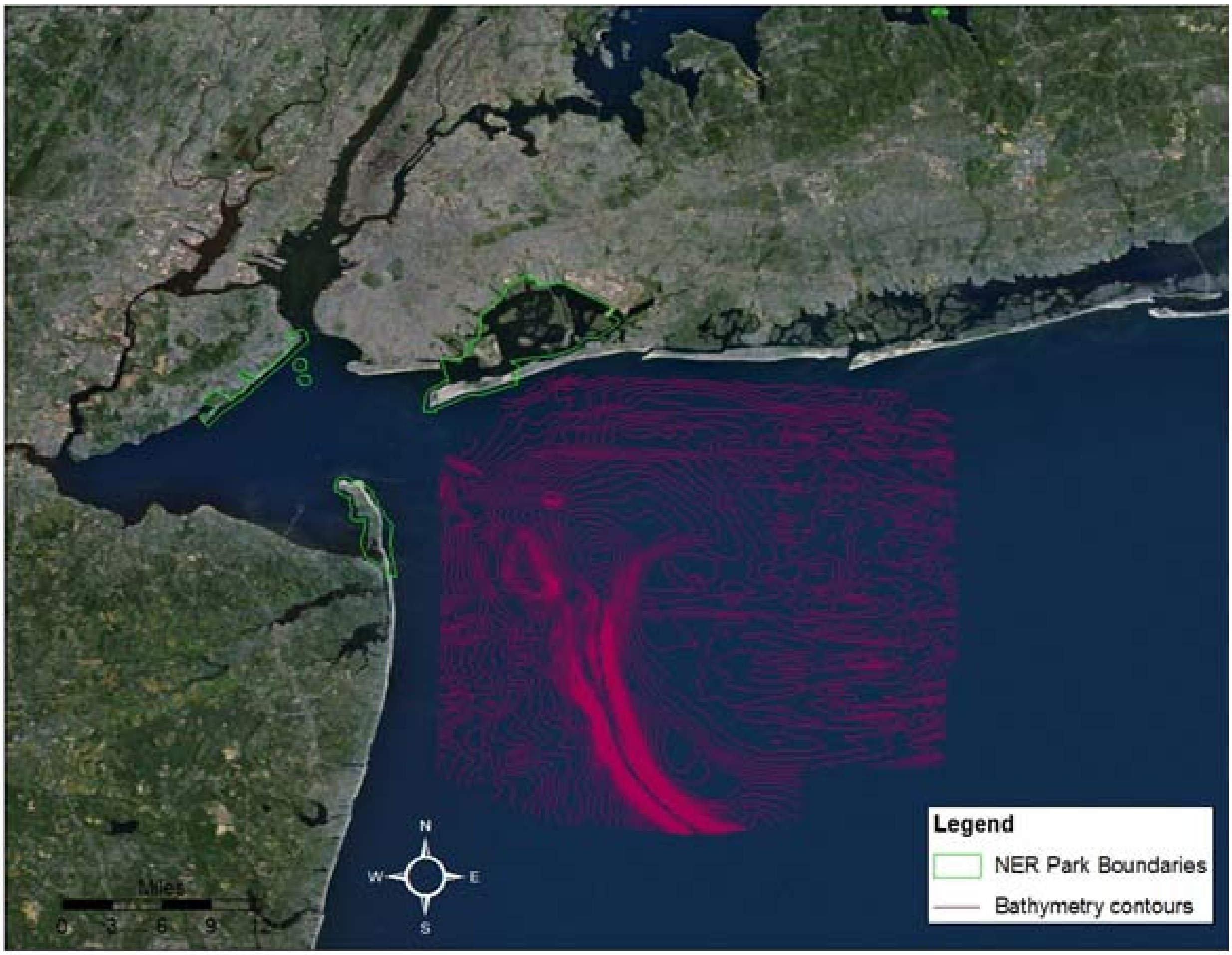

Figure 7. Bathymetry contours offshore of GATE. U.S. Geological Survey ASCII trackline bathymetry (Denny 2000).

<u>Hydrography</u>

Wave height, direction, and periodicity

Wave height data in the vicinity of GATE is collected by buoy 44065 (LLNR 725), owned and operated by the NOAA National Weather Service (NWS)'s National Data Buoy Center (NOAA NWS 2012b). This buoy is located 23 km east of Monmouth Beach, NJ and 24 km south of Long Beach, NY (Figure 8, Table 6).

Tide range, phase, and currents

Tide data are collected at nine stations (Figure 8, Table 6, NOAA NOS 2011). Three NOAA stations are in close proximity to GATE. Station 8531680 (SDHN4; Sandy Hook, NJ) is located on the west side of the Sandy Hook Unit, NJ at Fort Hancock within the seashore boundaries, and Stations 8517986 and n03020 are located within The Narrows, the tidal strait separating Staten Island and Brooklyn, NY, at the northern point of the Staten Island Unit. Two other NOAA stations are located upriver from the park boundary and may provide data less relevant for the park. Station 8530973 (ROBN4; Robins Reef, NY) is located approximately 1.6 km northeast of St. George NY, and Station 8519483 (BGNN4; Bergen Point West Reach, NY) is located 1.0 km southeast of Shooters Island, NY, near the Bayonne Bridge.

USGS station 1311875 is within the boundaries of the Jamaica Bay Unit at the Rockaway Inlet approximately 0.88 km southeast of Floyd Bennett Field, NY. Station 11311850 is within Jamaica Bay (east of park boundaries) at Inwood, NY. Station 140708 is closer to the Sandy Hook Unit at Waackaack Creek, NJ, approximately 10 km southwest of Fort Hancock, NJ (USGS 2012b).

Hydrogeologic framework

Hydrogeologic framework maps and data pertaining to GATE are available through the New York State (NYS) GIS Clearinghouse (NYS 2012b). The website provides access to marine and terrestrial geologic maps, digitized soil maps from the USDA Natural Resources Conservation Service (NRCS)'s Soil Survey Geographic Database (SSURGO; USDA NRCS 2001a); hazardous waste remediation sites tracked by the NYS Department of Environmental Conservation (DEC); a map of unconsolidated aquifers in New York State; aquifer maps at a 1:24,000 scale produced since the 1980s by the USGS Upstate New York Surficial Aquifer Mapping Program; and county-level bedrock geology, hydrologic framework, soils, erosion, estuary, and surficial geology maps.

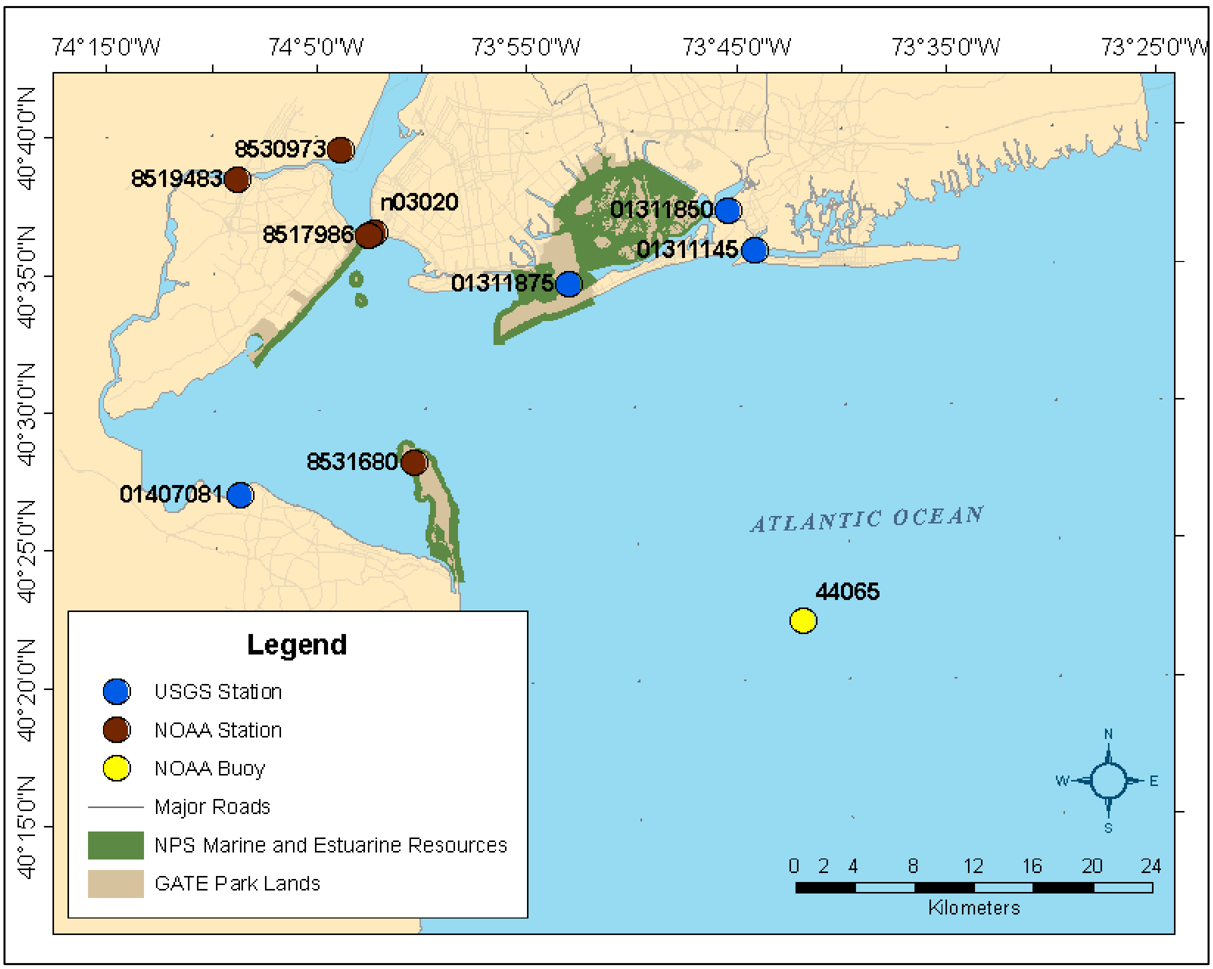

Figure 8. Moored buoys and stations collecting hydrographic data in the vicinity of Gateway National Recreation Area (NOAA NOS 2011, NOAA NWS 2012b, USGS 2012b).

Table 6. Hydrographic data collected by moored buoys and stations in the vicinity of Gateway National Recreation Area (NOAA NOS 2011, NOAA NWS 2012b, USGS 2012b).

GATE	**NOAA NDBC Moored Buoy**	**NOAA PORTS Stations**					**USGS Stations**			
Station Name	**LLNR 725**	**ROBN4**	**SDHN4**	**BGNN4**						
Station Code	**44065**	**8530973**	**8531680**	**8519483**	**8517986**	**n03020**	**01311875**	**01311145**	**01311850**	**01407081**
Wind Direction	+	+	+	+	-	-	-	-	-	-
Wind Speed	+	+	+	+	-	-	-	-	-	-
Wind Gust	+	+	+	+	-	-	-	-	-	-
Wave Height	+	-	-	-	-	-	-	-	-	-
Dominant Wave Period	+	-	-	-	-	-	-	-	-	-
Average Period	+	-	-	-	-	-	-	-	-	-
Mean Wave Direction	+	-	-	-	-	-	-	-	-	-
Atmospheric Pressure	+	-	+	+	-	-	-	-	-	-
Pressure Tendency	+	-	-	-	-	-	-	-	-	-
Air Temperature	+	+	+	+	-	-	-	-	-	-
Water Temperature	+		+	+	-	-	-	-	-	+
Dew Point	+	-	-	-	-	-	-	-	-	-
Water Level	-	+	+	+	+	-	+	+	+	+
Conductivity/Salinity	-	-	+	-	-	-	-	-	-	-
Currents	-	-	-	-	-	+	-	-	-	-

Bedrock geology and shallow stratigraphy
The NPS Geologic Resources Inventory (GRI) Scoping Report for GATE identifies sources of relevant geologic mapping data (Thornberry-Ehrlich 2011a; see also *National and Regional Datasets—Hydrogeologic framework*).

The New York State Museum Geologic Survey provides bedrock and surficial geology maps from the 1970s that incorporate GATE (Fisher et al. 1970; Cadwell 1989). The museum also maintains digital geology data.

Rutgers University, in cooperation with the NPS North Atlantic Coast Cooperative Ecosystem Studies Unit (NAC CESU), is undertaking a synthesis of GATE's coastal geomorphology and processes, but the project was not accessible for review at the time of this publication. The CESU project list provides a description of the synthesis effort (NAC CESU 2011).

In 1995, USGS began a partnership with the U.S. Army Corps of Engineers to map the seafloor of the New York/New Jersey Bight Apex. Through this program, high-resolution geophysical surveys were conducted over much of the New York Bight Apex from 1995 to 1998, with portions of the survey area lying just outside of GATE boundaries. Seafloor geophysical interpretations were based on sidescan acoustic sonar, sub-bottom profiling, and ground-truthing survey data (i.e., surface grab and vibracore sampling). Seismic tracklines and maps derived from interpretation of the sub-bottom profiles are available for download on the USGS Internet Map Server for New York Bight Inner-Continental Shelf (USGS 2008). These data provide a framework for evaluating sediment movement, dispersal, and erosion in this region. The program aims to provide a synthesis of the region's benthic environment, beach nourishment resources, and geologic framework, including sediment types and texture, morphology, geologic history, and stratigraphy (Schwab et. al. 2002). Publications and Internet resources pertaining to USGS seabed mapping in the New York Bight include, among others, Schwab et. al. 1997 (initial results), 2000a (seafloor characterization), and 2002 (seismic stratigraphy); and USGS 2008 (Internet map server), and 2002 (sidescan); and Lotto 1999 (seismic stratigraphy); see also *GATE—Acoustic seabed characterization* and *Bathymetry*.

Surface and groundwater pathways
In addition to localized sources below, data on surface-water level, stream flow, and groundwater level are provided by the USGS National Water Information System (USGS 2012b, see *National and Regional Datasets—Hydrogeologic framework*).

The USDA Natural Resources Conservation Service published soil maps and a soil survey of GATE (USDA NRCS 2001b). These products describe the park's surface waters, groundwater, water quality, and aquifers.

Incorporating the Jamaica Bay section of GATE, Misut and Monti (1999) present the results of a USGS simulation of ground-water flow and the effects of ground water pumping in Kings and Queens counties, Long Island, New York[207]. The investigation utilized a ground-water flow model with 406-m grid spacing to evaluate the effects of groundwater pumping. Analyses included the delineation of aquifer extent, thickness, and hydraulic characteristics; definition of recharge from precipitation and lateral inflow of ground water; and evaluation of discharge to streams, the shore, saltwater bodies, and wells. Static maps showing groundwater levels, wells, and modeling results are included in the report.

Buxton and Smolensky (1999) simulated the effects of development on groundwater flow in Long Island providing surface and groundwater predictions applicable to FIIS, as well as GATE and SAHI (see *National and Regional Datasets—Hydrogeologic Framework-Surface and groundwater pathways*).

An earlier three-page hydrologic investigations atlas (Smolensky et al. 1990) presents seven maps and vertical sections showing the hydrogeologic framework of deposits that form Long Island's ground-water system[204]. These include 1:250,000 scale maps showing the configuration of the bedrock surface, the altitude of Cretaceous deposits and bedrock beneath the upper glacial aquifer, and the altitude of the upper surface of the Raritan Confining Unit, Gardiner's clay, and the Lloyd, Monmouth, Jameco, and Magothy Aquifers. Hydrogeologic data from more than 3,100 wells were used to interpret the altitude of the upper surface of each hydrogeologic unit. Seismic survey data from previous studies were used to correlate onshore and offshore data and to project the extent of hydrogeologic units offshore. The atlas provides a description of the erosional and depositional history in Long Island derived from a theoretical sedimentation model and consequent interpretations of the type, location, and thickness of sediments.

Schubert et al. (1997) developed a four-page fact sheet, which evaluates ground-water resources in Long Island and describes techniques for simulating ground-water flow[205]. Relevant to FIIS (as well as GATE and SAHI), the fact sheet provides a description of Long Island's aquifers, stresses on the area's ground-water flow system, and patterns and rates of groundwater movements. In addition, the document presents information on Long Island's hydrogeologic framework, hydrologic boundaries, and hydraulic stresses, including the results of a particle tracking procedure used to define flow paths and delineate recharge areas. A GIS database was developed to incorporate model input, output, and particle tracking data.

Misut and Voss (2004) applied a three-dimensional model to simulate groundwater flow and the movement of the freshwater/saltwater interface on western Long Island. The model indicated a reduction in subsea freshwater discharge to Jamaica Bay from 1900 to 2004.

Historical shorelines
Historical shoreline data for the Sandy Hook area of GATE are available for select years from 1835 to 1998[72] (Leatherman and Mellander date unknown). The data are derived from a variety of sources and were compiled as part of a conditional assessment for the National Park Service. Historical shoreline data from four New Jersey counties were extracted from existing aerial photography and historic map sheets. The dataset includes: the Sandy Hook Shoreline Series for 1835, 1850, 1855, and 1932 digitized from 7.5-minute U.S. Coast Guard maps documenting historical shoreline changes in New Jersey; 1954 shoreline vector information for the northern portion of Sandy Hook derived from aerial photography; maps based on digitized aerial photography from 1984, 1986, 1988, 1990, and 1992; 1993 and 1994 2- to 5-m accuracy shoreline maps derived from GPS data; mean high water shapefiles for various years; polygons of beach fill operation locations along the New Jersey coast using data from the U.S. Army Corps of Engineers and the New Jersey Department of Environmental Protection (NJDEP)

dating from 1940 to 1992; and coastline/shoreline interface data interpreted from 1986 color-infrared photography and mylar overlays.

Staten Island shoreline data were recorded by GPS in 2005 and 2006 at multiple locations as part of an NPS Conditional Assessment project[73]. Sub-meter accuracy lines were mapped with a GeoXT GPS on foot and post processed with differential correction, using New Jersey Continuously Operating Reference Stations (CORS; NOAA National Geodetic Survey 2012) at Sandy Hook and Edison, New Jersey. Shapefiles of these shorelines were overlaid on 2002 aerial photography. The combined data are available as PDF files. These data do not have full metadata.

In 1993, the New Jersey Department of Environmental Protection (NJDEP) instituted a project to protect shoreline structures project. Through this project NJDEP plotted jetties, groins, revetments, sea walls, and breakwaters along the New Jersey coastline and its inland bays (NJDEP 1993). 1986 color infrared aerial photographs (1:58,000 scale) were inspected for shoreline protection structures. Findings were manually plotted on shoreline delineation basemaps within the NJDEP GIS database with a 1:24,000 spatial resolution (NJDEP 2011a). The resulting map of these structures is available online (NJDEP 2011b).

<u>Surficial geology</u>

Acoustic seabed characterization

The Marine Sciences Research Center of the State University of New York (SUNY) at Stony Brook completed seabed classification surveys in Jamaica Bay in 2008 and 2009 (see also *GATE—Bathymetry*). The data from this work were not available at the time of this publication. The project implementation plan proposes the use of multibeam echosounders and sidescan sonar to map deeper waters (greater than 2.5 m) with a minimum track spacing of 40 m; and single-beam echosounders to map shallower areas (about 0.5 m to 2.5 m) with survey lines spaced 40 m apart with 200-m cross-lines (Flood et al. 2008). Final GIS themes related to acoustic seabed characterization are proposed to include: 1-m grid multibeam backscatter, 1-m grid sidescan geotiff imagery, seabed classification benthic cover and geoform shapefiles, legacy backscatter data from 2000 and 2003 multibeam surveys, ancillary data, grain size sampling results, point files of penetrometer measurements of soil strength, and bottom images. Seabed classification will follow the CMECS approach and will be based upon acoustic properties of the seabed as well as discrete sampling data.

Also specific to Jamaica Bay, CR Environmental, Inc. and Marine Search and Survey performed seabed classification surveys in 2000 at several locations within Jamaica Bay (Little Bay, Norton Basin, the Raunt, and Grass Hassock Channel; CR Environmental, Inc. 2001). Surveyors operated a RoxAnn Seabed Classification System, a digital side-scan sonar system, and an underwater video sled to conduct the seabed classification surveys at all four locations. Side-scan sonar coverage was not obtained at the channel entrance to Norton Basin due to the operational depth limit of approximately 3 m. Seabed classification products included side-scan mosaics, Roxann bottom classifications, and bottom photographs of the survey areas.

In 2008, Rutgers University collected high-resolution imagery of benthic features at GATE's Kingman-Mills site at Sandy Hook, using side-scan sonar mounted on a REMUS autonomous underwater vehicle (AUV)[244] (Psuty and Silveira 2010; see also *GATE—Bathymetry*). High-resolution images were acquired along both sides of the path of the submersible covering an area measuring about 1400 m by 250 m. The datasets include the raw textfiles, shapefiles, side-scan sonar geotiff images, density maps, raster files, and JPEG images stored in a GIS database at GATE.

In 1995, USGS and the U.S. Army Corps of Engineers began a partnership to conduct high-resolution geophysical surveys over much of the New York Bight Apex, with portions of the survey area lying just outside of GATE boundaries (Schwab et al. 2002; see also *GATE—Hydrogeologic framework* and *Bathymetry*). Seafloor geophysical interpretations were based on sidescan acoustic sonar, sub-bottom profiling, and groundtruthing (i.e., surface grab and vibracore) data. Metadata for the sidescan imagery states that this mapping effort differs from previous studies of this area by obtaining sidescan-sonar images that cover 100% of the seafloor (USGS 2002). Preliminary interpretations of 1995 to 1996 data were presented in Schwab et al. (1997) and Lotto (1999) (Figure 9). Later reports present a composite mosaic of the sidescan-sonar imagery collected from 1995 to 1998 ((Schwab et al. 2000a; Schwab et al. 2002; Figure 10). Sidescan-sonar imagery combined with interpretations of surficial geology can be viewed online within Open File Report 00-295 (Schwab et al. 2000a).

In 1995, USGS began a partnership with the U.S. Army Corps of Engineers to map the seafloor of the New York/New Jersey Bight Apex. High-resolution geophysical surveys were conducted over much of the New York Bight Apex from 1995 to 1998, with portions of the survey area lying just outside of GATE boundaries. Seafloor geophysical interpretations were based on sidescan acoustic sonar, sub-bottom profiling, and ground-truthing survey data (i.e., surface grab and vibracore sampling). Survey tracklines and maps derived from interpretation of sidescan surveys are available for download on the USGS Internet Map Server for New York Bight Inner-Continental Shelf (USGS 2008). Preliminary interpretations of 1995 to 1996 data were presented in Schwab et al. (1997) and Lotto (1999). Later reports (Schwab et al. 2000a; Schwab et al. 2002) present a composite mosaic of the sidescan-sonar imagery collected from 1995 to 1998. The program aims to provide a synthesis of the region’s benthic environment, beach nourishment resources, and geologic framework, including sediment types and texture, morphology, geologic history, and stratigraphy (see also *GATE—Acoustic seabed characterization* and *Bathymetry)*.

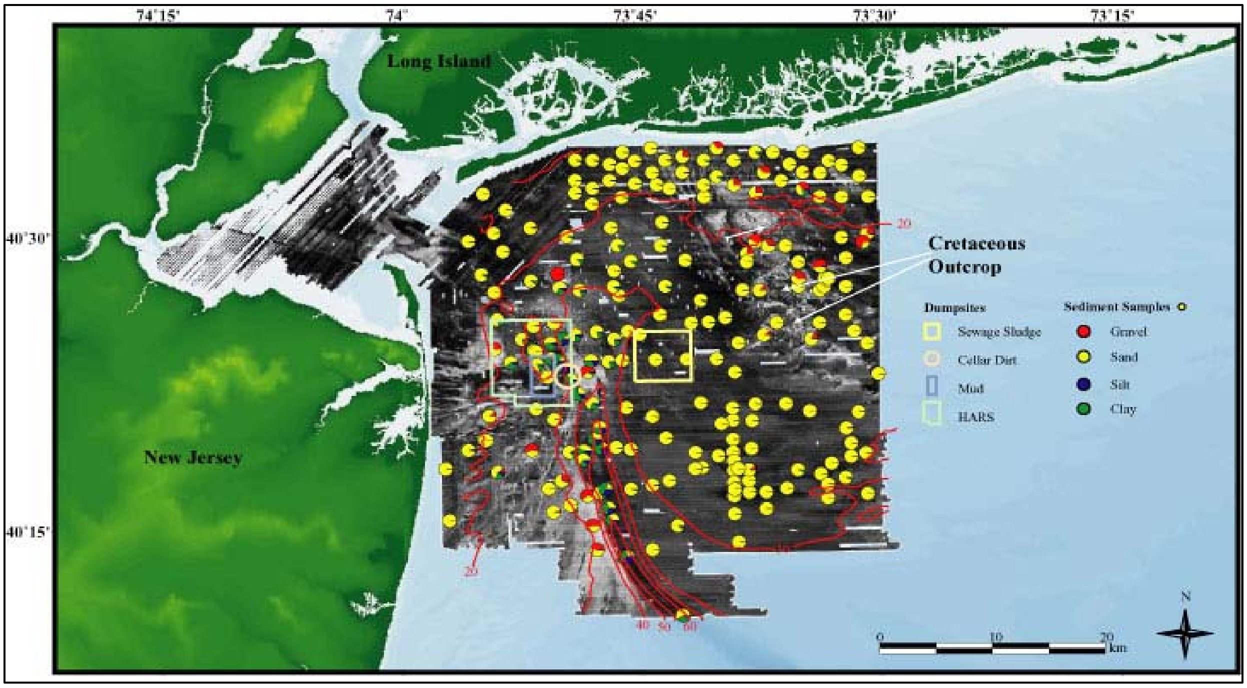

Figure 9. Sidescan-sonar imagery of the New York Bight Apex. From Schwab et al. (2002), USGS Open-File Report 02-152.

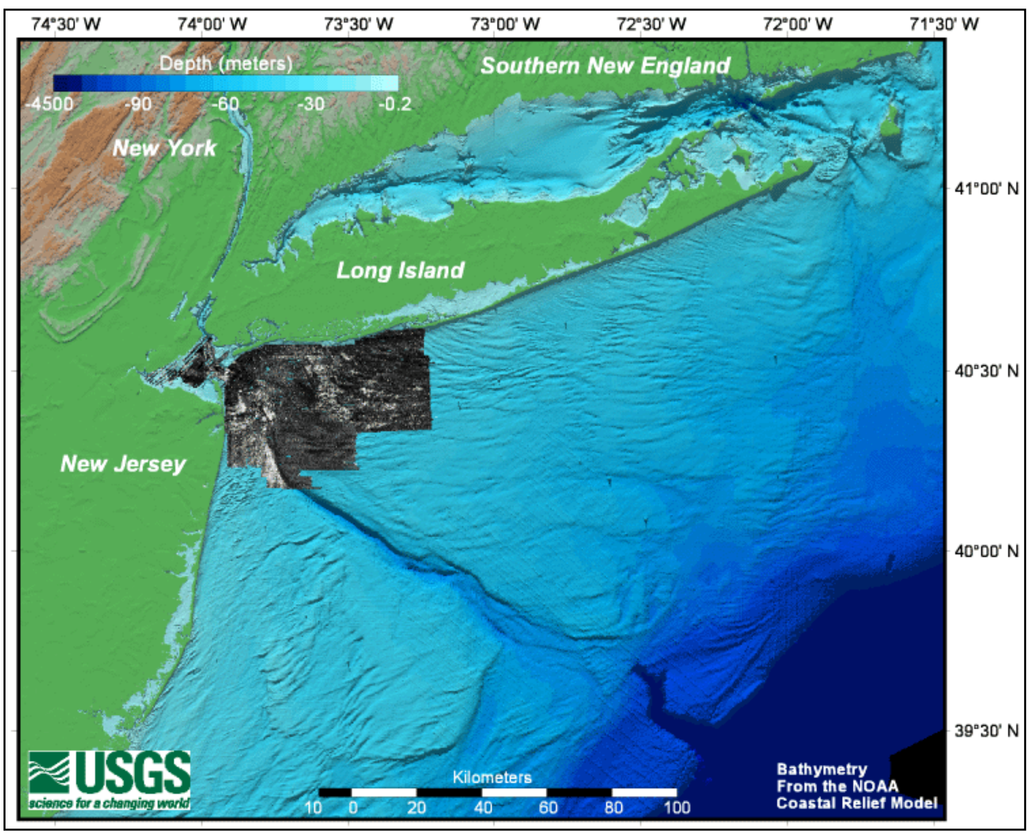

Figure 10. Backscatter intensity from sidescan sonar surveys in the New York Bight region (Schwab et al. 2000a).

Sediment grain size and organic content

Sediment grain size and organic content data for GATE consists of national and regional datasets such as EPA's NCA and NARS, CONMAP, usSEABED, the USGS Marine Aggregate Resources Project, and the East Coast Sediment Texture Database (see *National and regional Datasets—Sediment grain size and organic content*), as well as the following localized datasets.

The Marine Sciences Research Center of SUNY at Stony Brook completed seabed classification surveys in Jamaica Bay in 2008 and 2009 (see also *GATE—Acoustic seabed characterization*). The data from this work were not available at the time of this publication. In a 2010 emailed project update to the National Park Service, principal investigator Roger Flood reported that grab sampling and video were collected in 2009 at 85 locations within Jamaica Bay. Final GIS themes derived from discrete sampling and interpretive processes are proposed to include grain size sampling results, point files of penetrometer measurements of soil strength, and bottom images (Flood et al. 2008).

The USGS Marine Aggregate Resources Project (MARP) houses a GIS compilation of surficial sediment data for the New York-New Jersey region (Williams et al. 2006). The compilation is based on data contained within USGS Data Series 118 (Reid et al. 2005) and provides examples of GIS products that can be created using data compiled within usSEABED (Figure 11). This dataset was geographically clipped from the usSEABED database to include only samples within the New York-New Jersey region. Examples of metrics contained within the parsed (word-based) dataset include seafloor roughness, porosity, organic content, shear strength, color, grain size classification, and depth. Sampling points are contained within oceanside and bayside areas of GATE (USGS 2006; see also *FIIS—Sediment grain size and organic content*). Combining the parsed (word-based) and extracted (numerical, lab-based) usSEABED data for this region, 50 points fall within the Jamaica Bay section of GATE, 17 within the Raritan Bay section, and eight within the area of GATE surrounding Sandy Hook.

Also using usSEABED data, a regional assessment of marine aggregates was conducted for the New York Bight region using digital geologic maps developed for the region by USGS from usSEABED data (Williams et al. 2003). The New York Bight region was selected for the development of gridded or point maps of seafloor sedimentary character due its dense high quality data coverage.

EPA's Regional Environmental Monitoring and Assessment Program (R-EMAP) sediment composition dataset covers the New York/New Jersey Harbor and Bight Apex region[200] (Adams et al. 1998). The dataset reports the per cent silt/clay and total organic carbon (TOC) measured in grab samples taken in 1998 within the region's six sub-basins (see also *GATE—Water chemistry and water quality*). Grab samples reached a maximum 10-cm depth penetration into the sediment.

In 1994 and 1995, the U.S. Army Corps of Engineers and NOAA Coastal Services Center analyzed grab samples for sediment grain size and organic content in the Lower and Upper Bays of the New York/New Jersey Harbor [40, 41] (NOAA CSC and USACOE 2000). The project was part of a larger effort to develop benthic habitat maps for the Upper and Lower Bays of New York Harbor, Raritan Bay, and Sandy Hook Bay (see also *GATE—Submerged habitats and biological communities*). Samples from 49 stations in Upper Bay, Jamaica Bay, and Flushing

Bay were collected in 1994 and 1995 using a Shipek grab. An additional 189 sample points were established between Staten Island and Sandy Hook. The grab sample data are available online (NOAA CSC 2012). Grab sample data were compared with sediment profile images as part of sediment classification and an analysis of physical, chemical, geological, and biological conditions at each station.

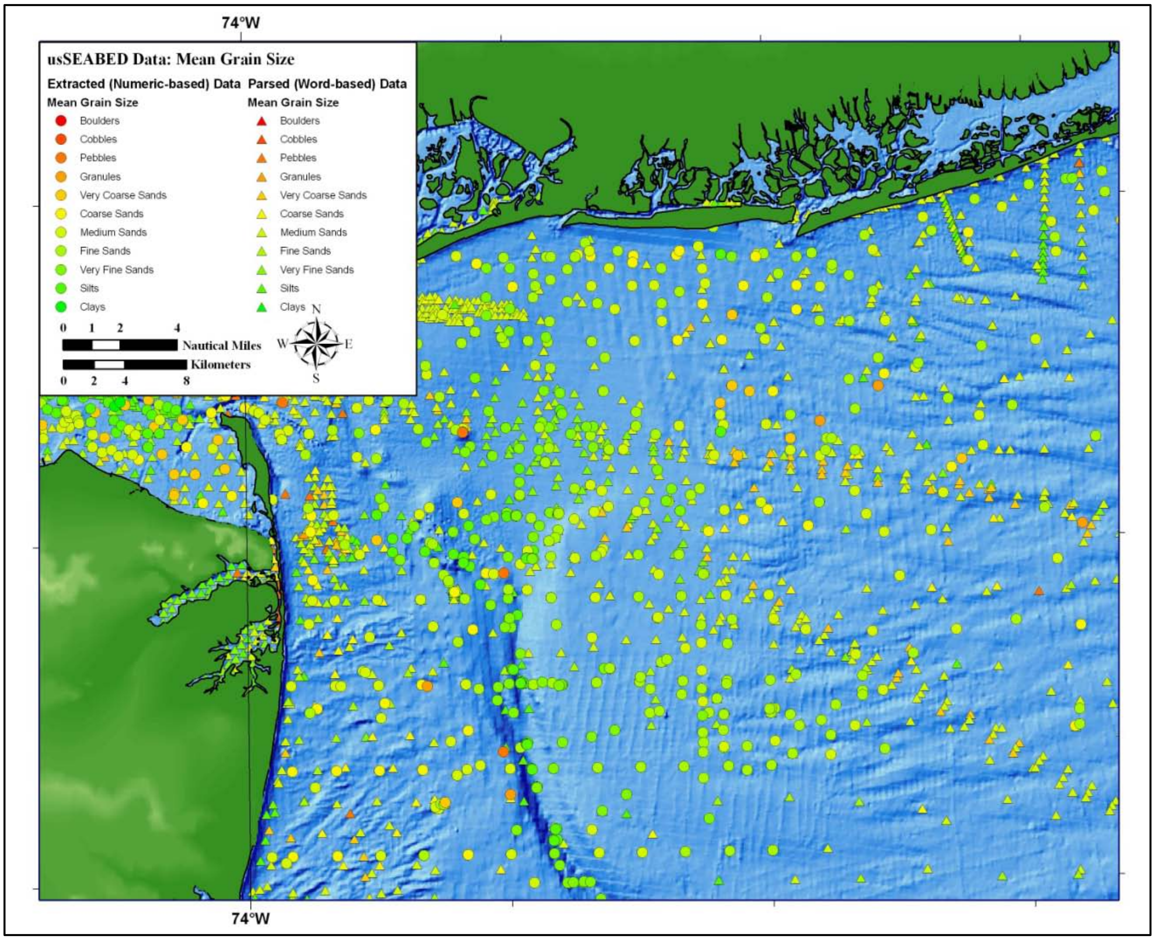

Figure 11. Surficial sediment character of the New York-New Jersey offshore Continental Shelf region; a GIS Compilation (Williams et al. 2006).

<u>Sediment contaminants</u>

Sediment contaminants data for GATE consist of national/regional datasets generated by EPA's NCA and NARS programs (see *National and regional Datasets—Sediment contaminants*), as well as the following localized datasets.

The Marine Sciences Research Center at SUNY Stony Brook collected sediment contaminant data in Jamaica Bay as part of a larger bathymetry mapping and seabed classification program (see also *GATE—Bathymetry and Acoustic seabed characterization*). The data from this project were not available at the time of this report's publication. Sediment contaminant and distribution data will be extracted from grab samples (Flood et al. 2008).

The 1993/1994 and 1998/1999 New York/New Jersey Harbor R-EMAP projects provided a baseline for the areal extent of chemical contamination within the Harbor system and the New York/New Jersey Bight Apex (Adams and Benvi 2003[199]; Adams et al. 1998[200]). In 1993/1994, 168 sites within six sub-basins were sampled including: Upper Harbor, Newark Bay, Lower Harbor (Raritan and Sandy Hook Bays), Jamaica Bay, western Long Island Sound and the New York Bight Apex. At each site, surficial sediment contaminant concentrations, two sediment toxicity tests (*Ampelisca adbita* and *Microtox)*, and benthic macrofaunal community structure were measured (see also GATE *Water Quality* and *Benthic Communities)*. Physical and chemical analyses included PAHs, PCBs, pesticides, major and trace elements, hexavalent chromium, dioxins and furans, AVS/SEM, butyltins, total organic carbon, and grain size. A Young-modified van Veen grab was used to collect surficial sediment and benthic macroinvertebrate samples. In 1998, 112 sites were sampled in four sub-basins: the Upper and Lower Harbor, and Newark and Jamaica Bays.

The EPA STOrage and RETrieval (STORET) Data Warehouse (EPA 2012b) database contains regional contaminant data for the New York/New Jersey Metro Area and Long Island Sound region[198] (NJDEP 2005). The STORET data management system is an EPA national database containing raw biological, chemical, and physical data on surface and ground water. The New York/New Jersey Metro Area dataset includes sediment contaminant data (as well as water-quality data; see *GATE—Water Quality*) collected from 1965 to 1989 by NPS and state entities[197] (EPA 2006). This dataset includes 8 sampling points in the Staten Island portion of GATE, 12 in the Sandy Hook portions, and another 10 sampling sites in near vicinity of the park. The Long Island dataset includes sediment contaminant data (as well as water-quality data) collected by the State of New York and NPS from 1965 to 2005 from four New York counties (Kings, Queens, Nassau, and Suffolk) and Monmouth County, New Jersey (EPA 2007). This dataset provides STORET data pertinent to the Jamaica Bay section of GATE. The data were downloaded from EPA STORET, converted to GIS, and organized in a geodatabase with associated metadata. The data resolution is fine enough for specific park use.

Water chemistry and water quality

Water-chemistry and water-quality data for GATE consist of national/regional datasets (see *National and regional Datasets—Water chemistry and water quality*), as well as the following localized datasets.

As part of a 2008 survey of bottom and water column measurements, Rutgers University collected water temperature, salinity, and oxygen saturation data at GATE's Kingman-Mills site at Sandy Hook using Conductivity-Temperature-Depth and Dissolved Oxygen sensors mounted on a REMUS autonomous underwater vehicle (AUV)[245] (Psuty and Silveira 2010). The survey covered an area measuring about 1400 m by 250 m. The datasets include the raw textfiles, shapefiles, density maps raster files, and JPEG images and are stored in a GIS database at GATE (Psuty and Silveira 2010, Fig 5-7, p. 9-11). Water temperature and salinity measurements were taken every four seconds along the track line, and oxygen saturation measurements were taken every second.

In 1993/1994, water quality vertical profile data were collected in six sub-basins through the New York/New Jersey R-EMAP program (Adams and O'Connor 1997; Adams and Bevi 2003[199]). Measurements included surface and bottom water temperature, dissolved oxygen, salinity, and pH. In 1998-1999, the same water quality parameters and also Secchi depth were sampled in four of the six sub-basins (Adams and O'Connor 2004). A SeaBird SBE "Sealogger" CTD unit was used to obtain a vertical profile of depth, dissolved oxygen, pH, temperature, and salinity at each station. Dissolved oxygen, temperature, and surface salinity were measured using a Winkler titration, NBS thermometer, and refractometer and compared with the CTD results. In both projects, the study area extended from the ocean to the lower portions of major tributaries upstream to a near-bottom salinity of 15 ppt. The water-quality datasets are available online and are organized into a geodatabase (EPA 2010c). These REMAP projects were designed to support resource management decisions related to pollution control and remediation throughout the New York/New Jersey Harbor and Bight Apex.

The EPA STORET database (EPA 2012b) contains regional water-quality data for the New York/New Jersey Metro Area[198] and Long Island Sound[197] region (NJDEP 2005). Water-quality data include surface and bottom temperature, dissolved oxygen, salinity, and pH. The New York/New Jersey Metro Area dataset was collected from 1965 to 1989 by NPS and state entities. This dataset includes 8 sampling points within the Staten Island portion of GATE, 12 in the Sandy Hook portion, and another 10 sampling sites in the vicinity of the park (EPA 2006; see also *GATE—Sediment contaminants*). The Long Island dataset includes 15 sampling points in the Jamaica Bay section of GATE and is based on water-quality data collected by the State of New York and NPS from 1965 to 2005 (EPA 2007). This dataset provides STORET data pertinent to the Jamaica Bay section of GATE and FIIS. The data were downloaded from EPA STORET, converted to GIS, and organized in a geodatabase with associated metadata.

The City of New York has been collecting water-chemistry and water-quality data in New York Harbor since 1909; responsibility for the Harbor Survey Program resides currently with the New York City Department of Environmental Protection's Marine Sciences Section[98] (NYC DEP 2012). The Survey is conducted weekly from June through September and every other week from October through May. Parameters evaluated include salinity, temperature, pH, fecal coliform and *Enterococcus* bacteria, dissolved oxygen, chlorophyll a, light transmission (Secchi transparency and photsynthetically active radiation at surface and depth), and nutrients. The Survey consists of 62 stations, 35 of which are located throughout the open waters of the Harbor. There are 22 stations in Jamaica Bay with relevance to GATE Jamaica Bay unit and 5 stations in lower New York Bay with relevance to GATE Staten Island unit. Data and annual reports are publicly available (NYC DEP 2012).

Submerged habitats and biological communities

Biological communities and species inventories

In 1994 and 1995, the U.S. Army Corps of Engineers and NOAA Coastal Services Center developed benthic habitat maps for New York Harbor, Lower Bay, Raritan Bay, and Sandy Hook Bay as part of the planning for dredge material disposal and habitat restoration[40] (NOAA CSC and USACOE 2000). Sediment profile images of the sediment-water interface were collected at all intersections along a 500-m^2 grid where water depth was deeper than 3 m. The images were visually analyzed for physical, chemical, geological, and biological conditions at each station and habitat features were categorized into one of the five habitat classes defined by sediment type and/or faunal community. Benthic grab samples were collected concurrently using a Shipek grab. The grab sample data are available online (NOAA CSC 2012). Displayed in GIS, the composite data were used to characterize benthic habitat types for the New York/New Jersey

Harbor. Attribute accuracy was verified by checking the compiled SPI database against the actual photos for each station. Results of grab sampling were also used to check the accuracy of the sediment profile image dataset.

EPA's Regional Environmental Monitoring and Assessment Program (R-EMAP) used an adaptation of the EPA EMAP approach (EPA 2010b) to assess specific regions. The 1993/1994 and 1998/1999 New York/New Jersey Harbor R-EMAP projects aimed to define the areal extent of chemical contamination and biological effects within the Harbor system and the New York/New Jersey Bight Apex (Adams and Benvi 2003[199]; Adams et al. 1998[200]). Benthic macroinvertebrate samples were taken using a Young-modified van Veen grab. In 1993/1994, benthic infaunal community structure was assessed at 168 sites within six sub-basins: Upper Harbor, Newark Bay, Lower Harbor (Raritan and Sandy Hook Bays), Jamaica Bay, western Long Island Sound and the New York Bight Apex. In 1998, 112 sites were sampled in four of the six sub-basins (the Upper and Lower Harbor and Newark and Jamaica Bays) using a study design and methods parallel to the 1993/1994 investigation. The reports discuss the association between contaminant levels and benthos condition. A biotic index was developed for assessing the quality of benthic infaunal communities. Data for both projects are organized in a geodatabase.

Wetland and vegetation classification and mapping was conducted at GATE by the NPS Inventory and Monitoring Program using USGS/NPS National Vegetation Mapping protocol (Edinger et al. 2008). The effort produced a digital geospatial vegetation database for the park, a species list, dichotomous key, and descriptions of vegetation associations within park boundaries. Vegetation maps for Jamaica Bay, Sandy Hook, and Staten Island park units were created through interpretation of aerial photomosaics. The report contains results of surveys conducted in 2003 and 2004 at 119 vegetation plots within the Jamaica Bay unit of GATE, 22 plots in the Staten Island unit, and 37 plots in the Sandy Hook unit. Positional accuracies of the digital photomosaics were assessed at 2.40 m, 2.08 m, and 3.25 m for Jamaica Bay, Sandy Hook, and Staten Island, respectively. The report lists sources used for refining photo interpretation as: soil maps (NRCS 2001b); the NY State Soil Survey Geographic Database; bedrock and surficial geology maps (Fisher et al. 1970; Cadwell et al. 1989; the New York State Museum digital geology data; wetland maps (National Wetland Inventory data for New York State; New York State Regulatory Freshwater Wetland data); state tidal wetland maps (New York Department of State, Division of Coastal Resources); and the New York and New Jersey Natural Heritage Program Biotics databases.

Cape Cod National Seashore (CACO)

The Massachusetts Ocean Resources Information System (MORIS) is an online mapping tool that compiles geological, physical, and biological data for the Massachusetts coastal zone into an interactive geospatial database (MA CZM 2011). MORIS was created by the Massachusetts Office of Coastal Zone Management (MA CZM), the Massachusetts Office of Geographic Information (MassGIS), and a number of additional partners. MORIS is a primary source and compilation of data pertaining to CACO including bathymetry, hydrographic features, hydrography, surficial sediments, geologic framework, water quality, and biological data layers.

Users can interactively view such data layers overlaid on aerial photographs or various basemaps.

The Official Website of the Office of Geographic Information (MassGIS 2012) includes a GIS database that houses all of Massachusetts digital GIS data. The database and datalayers include aerial photography, topographic reference maps, surficial geology basemaps, elevation data, digital elevation models, coastal and marine features data (including MORIS layers, beaches, tidelands, fish and shellfish, wetlands, etc.), rare species, protected habitats, environmental monitoring, soils, hydrography, and other relevant data.

Bathymetry

National, regional, and localized datasets provide full bathymetric coverage of CACO at varying resolutions; however, at the time of this publication, modern, high-resolution, continuous coverage acoustic bathymetric data were not available for the full extent of sub-tidal areas within the park. The following data descriptions represent the existing local and park-specific datasets available for CACO at the time of the inventory's completion, as well as a number of additional bathymetry datasets acquired post-inventory. Descriptions of national and regional datasets relevant to CACO are included in the *National and Regional Datasets—Bathymetry* section.

The NOAA Estuarine Bathymetry Project website (NOAA 2007) features a digital raster compilation of NOS hydrographic soundings data for Cape Cod Bay[234] (NOAA NOS 1998f). Bathymetry maps of Cape Cod Bay were derived from 15 hydrographic surveys dating from 1933 to 1971 and containing 139,022 soundings covering depths 1.8 m above mean low water to approximately 60 m below mean low water (Figure 12). The average separation between soundings was 102 m. Products include 21 7.5-minute DEMs (3-arc-second) and three 1-degree DEMs. This compilation of pre-1972 sounding data covers the full extent of sub-tidal areas within the Cape Cod Bay section of CACO.

Available on the NOAA National Geophysical Data Center website is a 1/3-arc-second integrated bathymetric and topographic DEM for Nantucket, Massachusetts[1] (Eakins et al. 2009). While focused on Nantucket, the DEM extends northward to include integrated bathymetry and topography for a portion of the southern extent of CACO (Figure 13). The coordinate boundaries of the DEM are 69.49° to 70.67°W and 40.81° to 41.71°N. Bathymetric datasets used in the compilation included NOS hydrographic surveys (1989-2004), USGS multibeam swath sonar surveys (1998-2004), extracted NOAA Electronic Nautical Charts sounding data (2006-2007), the U.S. Army Corps of Engineers hydrographic harbor surveys (2004-2007), and Digital Globe satellite imagery (2008). Positional accuracy of USGS and NOS multibeam and U.S. Army Corps of Engineers hydrographic surveys is 5 m. Sparser 20th century NOS hydrographic soundings are accurate to several hundred m. Vertical accuracy of USGS and NOS multibeam sonar surveys is 0.1 to 1 m, whereas that of NOS hydrographic soundings is several m. While covering a relatively small extent of the park (about 8 km by 1 km), this dataset incorporates various data sources that represent current, continuous coverage, and high-resolution acoustic bathymetry data.

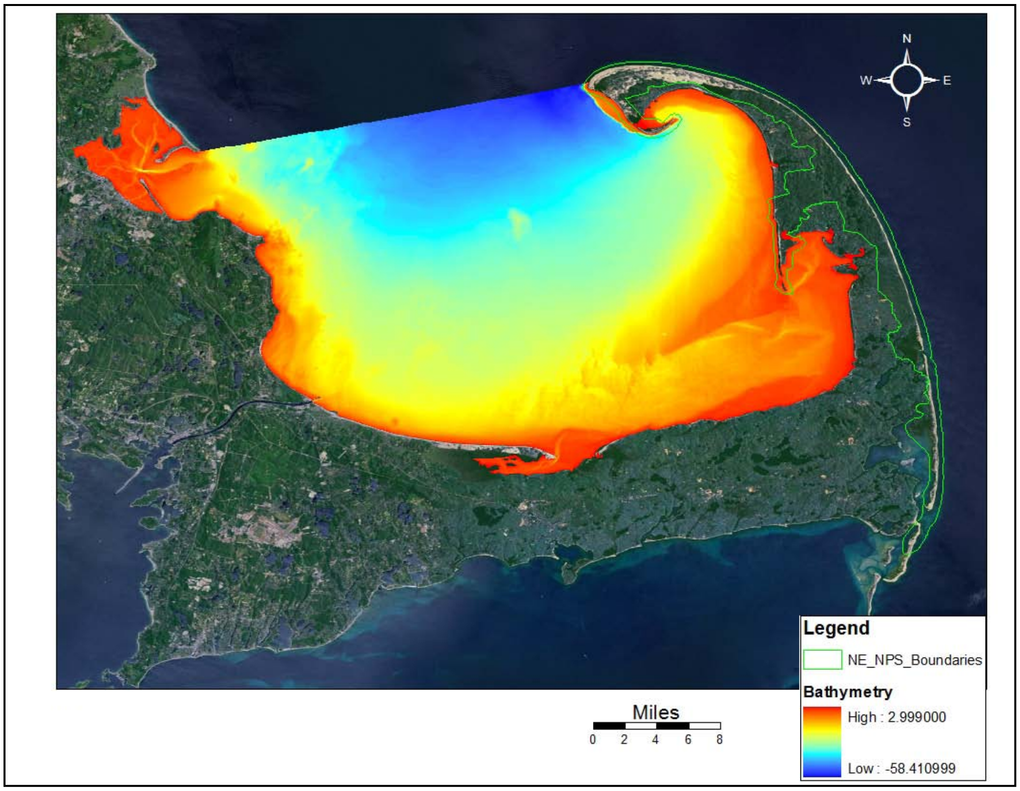

Figure 12. NOAA digital raster compilation of National Ocean Service hydrographic soundings for Cape Cod Bay (NOAA 2007).

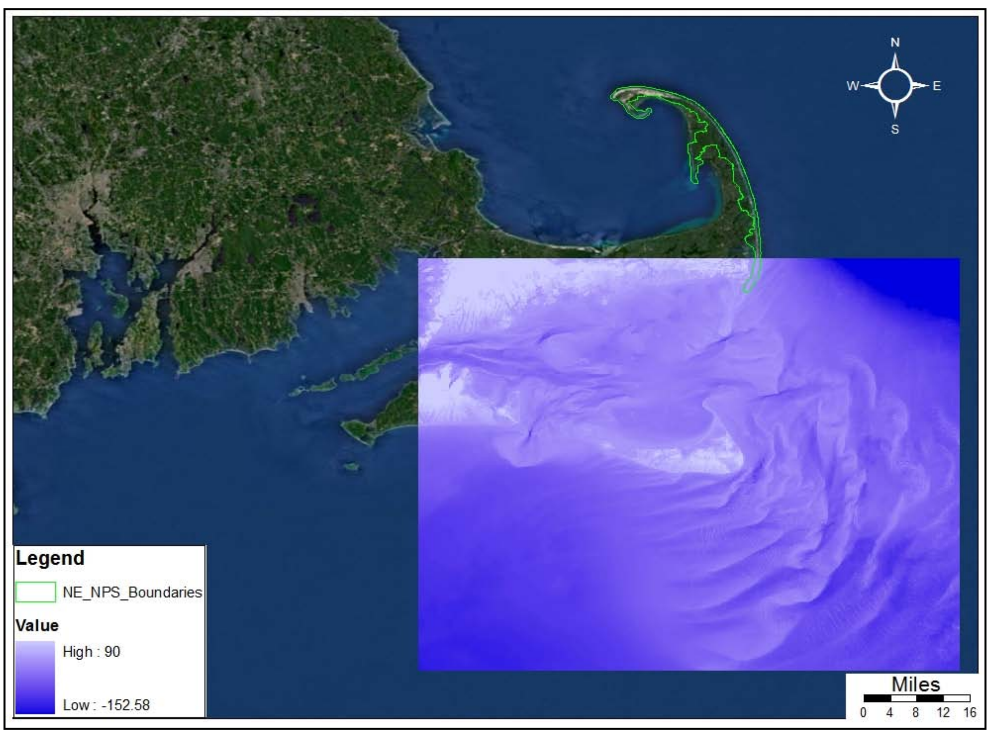

Figure 13. 1/3-arc-second integrated bathymetric and topographic DEM for Nantucket, MA, encompassing the southern extent of CACO (Eakins et al. 2009).

In 2008, MA CZM published a 30-m resolution mosaic of bathymetric datasets for all waters off the coast of Massachusetts, derived from “the most current and accurate sources”[236] (MA CZM 2008). The mosaic is a compilation of bathymetric data varying in resolution from 2 to 90 m from USGS Open-File Reports, the NOAA Estuarine Bathymetry Project[234] (NOAA 2007), and the NOAA NGDC Coastal Relief Model for the Northeast (NOAA NGDC 1999b). The data were developed to form a continuous bathymetric model for Massachusetts waters, covering the entire geographic extent with no known omissions (Figure 14).

In 1998, USGS conducted a multibeam swath sonar survey (Survey 90815) along approximately 153 km^2 of the seafloor offshore of Eastern Cape Cod [211, 231, 233] (Poppe et al. 2005b). Bathymetric data from this survey were compiled into 4-m grids. The horizontal resolution of the beam on the seafloor was about 10% of water depth and vertical resolution was about 1% of water depth. Basic data layers show seafloor topography and sun-illuminated shaded relief. This high-resolution acoustic dataset overlaps with a thin strip of the park (less than 0.3 km wide) along several lengths of CACO’s bayside extent (totaling about 8 km combined length; Figure 15).

The NOAA Coastal Services Center published coastal topographic and bathymetric lidar survey data for Maine, Massachusetts, and Rhode Island (NOAA CSC 2009; see also *National and Regional Datasets—Bathymetry*). The survey footprint and metadata (JALBTCX 2009) can be viewed on the NOAA Coastal Services Center Digital Coast Data Access Viewer (NOAA CSC 2012).

The Pleasant Bay estuary, located at the “elbow” of Cape Cod, is the largest coastal embayment on Cape Cod. The eastern portion of the bay bordering the barrier beach is within the seashore boundary. A new inlet that was formed in the barrier beach in April 2007 had considerable impact on the bathymetry of the lower portion of the bay. In July 2008, Applied Coastal Research and Engineering, Inc. developed a post-breach bathymetric map based on lidar bathymetry and topography data collected during two separate surveys flown in April and October 2007 by the U.S. Army Corps of Engineers (Kelley and Ramsey 2008).

The Provincetown Center for Coastal Studies is using interferometric sonar to gather coincident swath acoustic backscatter and bathymetric data in nearshore eastern Cape Cod Bay (in 2 m out to 10 m of water) between Provincetown Harbor and Wellfleet, MA (PCCS 2012). The final mapping products were not available at the time of this report.

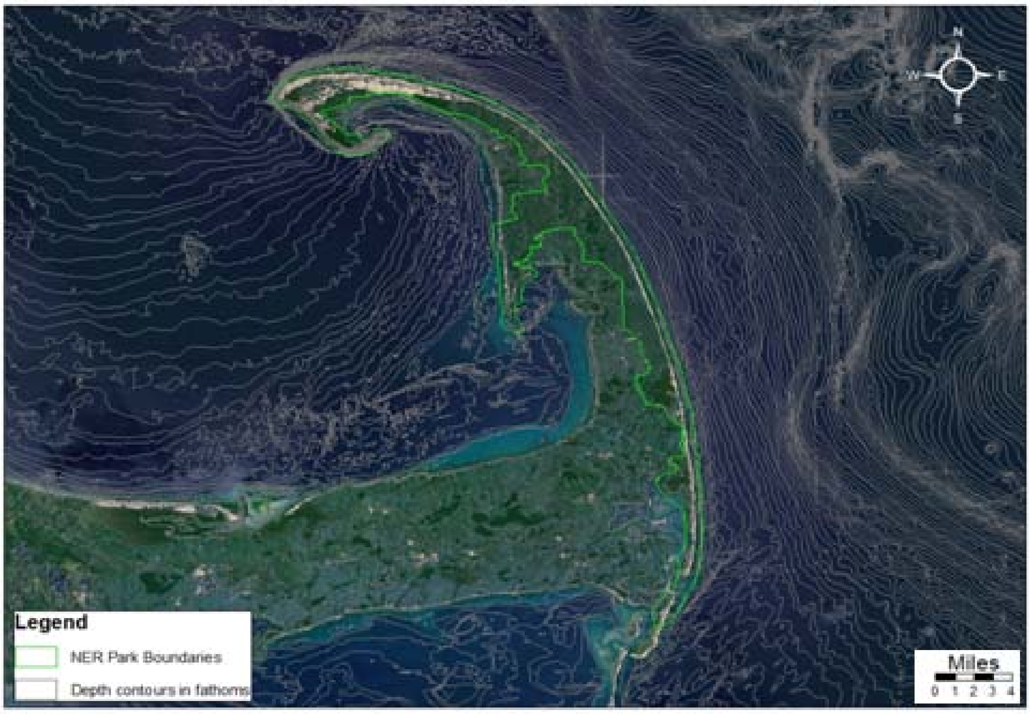

Figure 14. Bathymetric mosaic for all Massachusetts waters. Massachusetts Office of Coastal Zone Management (MA CZM 2008).

Figure 15. USGS multibeam swath sonar bathymetry survey offshore of Cape Cod (Poppe et al. 2005b)

Hydrography

Wave height, direction, and periodicity

Data for wave height, direction, and periodicity in the vicinity of CACO is provided by NOAA National Data Buoy Center moored buoy 44020 (LLNR 13665, Nantucket Sound main channel lighted gong buoy 17, NOAA NWS 2012b), located within Nantucket Sound 15 km SE of South Yarmouth on Cape Cod (Figure 16, Table 7) .

Tide range, phase, and currents

Water level data are collected at NOAA NOS station 8447435, located at the southern end of Pleasant Bay on the shore of Chatham, Massachusetts (Figure 16, Table 7, NOAA NOS 2011). In addition, water level is recorded continuously at the upper end of Pleasant Bay, in Meetinghouse Pond, by the Cape Cod National Seashore – Long Term Ecosystem Monitoring Program. There is no active NOS real-time current monitoring station in the vicinity of the park.

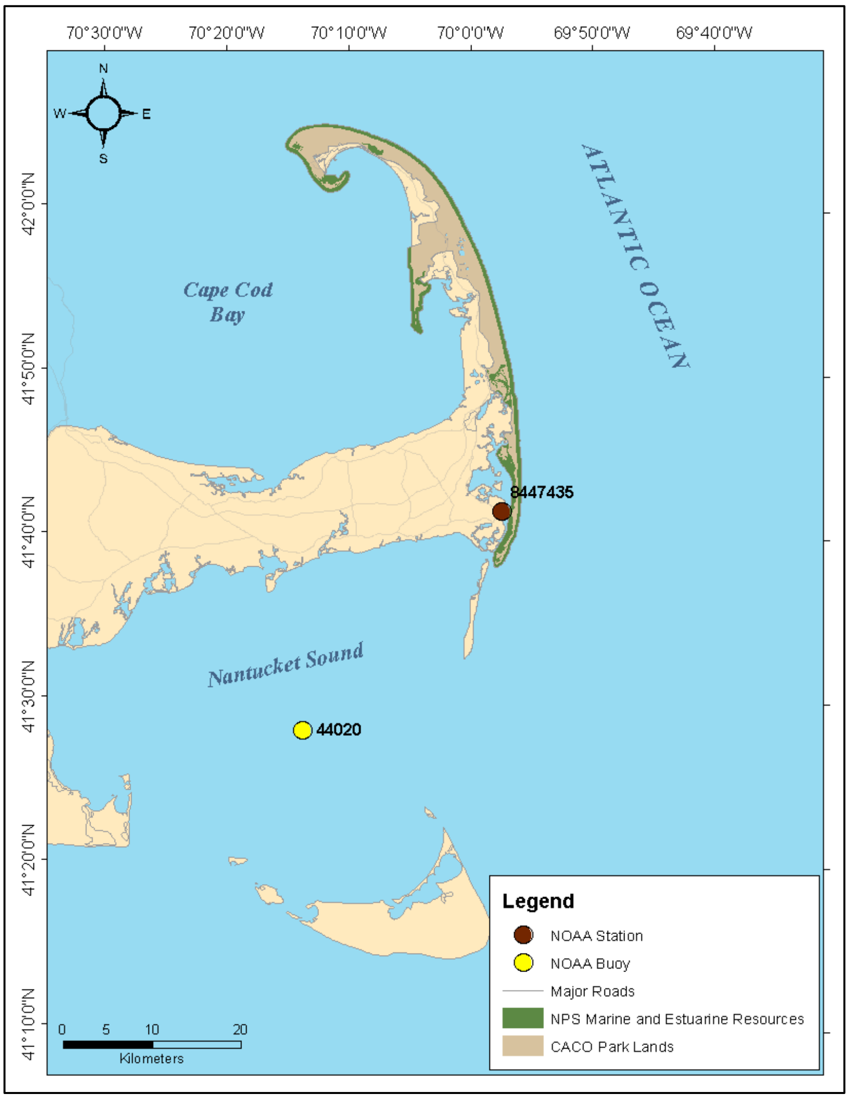

Figure 16. NOAA hydrographic data stations in the vicinity of Cape Cod National Seashore (NOAA NOS 2011, NOAA NWS 2012b).

Table 7. Hydrographic data collected by moored buoys and stations in the vicinity of Cape Cod National Seashore (NOAA NOS 2011, NOAA NWS 2012b).

CACO	NOAA NDBC Moored Buoy	NOAA NOS Stations
Station Name	**LLNR 13665**	
Station Code	**44020**	**8447435**
Wind Direction	+	-
Wind Speed	+	-
Wind Gust	+	-
Wave Height	+	-
Dominant Wave Period	+	-
Average Period	+	-
Mean Wave Direction	+	-
Atmospheric Pressure	+	-
Pressure Tendency	+	-
Air Temperature	+	-
Water Temperature	+	-
Dew Point	+	-
Water Level	-	+
Conductivity/Salinity	-	-

Hydrogeologic framework

Surface and groundwater pathways

In addition to localized sources below, data on surface-water level, stream flow, and groundwater level are provided by the USGS National Water Information System (USGS 2012b, see *National and Regional Datasets—Hydrogeologic framework*).

Masterson (2004) reports on modeling studies of the lower Cape Cod aquifer system, simulating the effects of ground-water pumping, sea-level change, and salt and fresh water interactions. Masterson and Portnoy (2005) synthesize potential changes in groundwater flow and their effects on CACO resources.

Bedrock geology and shallow stratigraphy

The NPS Geologic Resources Inventory (GRI) Scoping Report for CACO provides a detailed evaluation of available geologic data sources (Graham 2008; *see National and regional Datasets—Hydrogeologic framework*). Scoping meeting participants determined that existing geologic maps provide adequate coverage and detail for use by resource management. The GRI will combine portions of existing maps to produce a seamless digital geologic map of CACO. In addition, List et al. (2006) discuss erosional hotspots along the sandy shoreline of CACO.

Surficial geology

Acoustic seabed characterization

In 1998, USGS collected about 153 km^2 of multibeam backscatter intensity data for geological interpretation of the seafloor off Eastern Cape Cod[233] (Poppe et. al. 2005b; see also *CACO—*

Bathymetry). Ground-truthing data, in the form of surficial sediment samples, video, and still photography, were collected at 89 stations in 2004. Historical grain size analyses and photo galleries were incorporated into the ground-truthing dataset to aid interpretation of seabed composition, sedimentary structures, faunal communities, and bottom variability (Poppe et. al. 2003). Surficial sediment interpretations were based on the Wentworth (1922) grain size scale and Shepard (1954) sediment classification scheme, as modified by Schlee (1973). Backscatter intensity measurements of seafloor hardness and roughness were combined with sun-illuminated topography to create pseudo-colored imagery. Products include a 4 m/pixel resolution basic backscatter intensity data layer and interpretive maps showing the distributions of surficial sediments and sedimentary environments. An online GIS data catalog includes backscatter imagery, bathymetry, a gallery of bottom photographs, interpretive surficial sediment and geology data layers, and basemaps. The dataset overlaps with three segments of the northern, bayside extent of CACO, each less than 0.3 km wide and totaling a combined length of about 8 km.

The Provincetown Center for Coastal Studies is using interferometric sonar to gather coincident swath acoustic backscatter and bathymetric data in nearshore eastern Cape Cod Bay (in 2 m out to 10 m of water) between Provincetown Harbor and Wellfleet, MA (PCCS 2012). The final mapping products were not available at the time of this report.

Sediment grain size and organic content

Sediment grain size and organic content data for CACO consists of national and regional datasets such as EPA's NCA and NARS, CONMAP, usSEABED, the USGS Marine Aggregate Resources Project, and the East Coast Sediment Texture Database (see *National and Regional Datasets—Sediment grain size and organic content*), as well as the following localized data sources.

In addition to a regional overview map for the northeastern U.S. (see *National and Regional Datasets),* the USGS Marine Aggregate Resources and Processes Projects database contains a compilation map specific to the Cape Cod Bay region (Poppe et al. 2003). The map compiles multiple projects that contain sampling sites within or in the vicinity of CACO, including:

(1) the East Coast Sediment Texture Database and CONMAP (see *National and Regional Datasets*);
(2) the Maine Inner Continental Shelf Sediment data (Figure 17, Poppe and Hastings 2003);
(3) 1938 data from the first systematic grab sampling in the U.S. Atlantic margin (2 of the 9 traverses pertain to CACO) (Stetson 1938);
(4) a clipped version of the Smithsonian Institution Master Sediment data file, which contains information from archival samples submitted by various entities from 1965 to 1990 for the Gulf of Maine, Georges Bank, and southeastern New England (Smithsonian Institution 2012);
(5) a 1:100,000 scale map and data describing the areal distribution of major bottom sediment types covering the seafloor off Massachusetts between Cape Ann and Cape Cod (Schlee et al. 1973).
(6) NOS hydrographic sampling data from 1869 to 1985 and NOS cartographic codes for bottom characteristics no longer readily available on the NOAA NGDC site for

interpretation of surficial sediment distributions. Three sampling stations within this dataset are within 10 km of CACO.

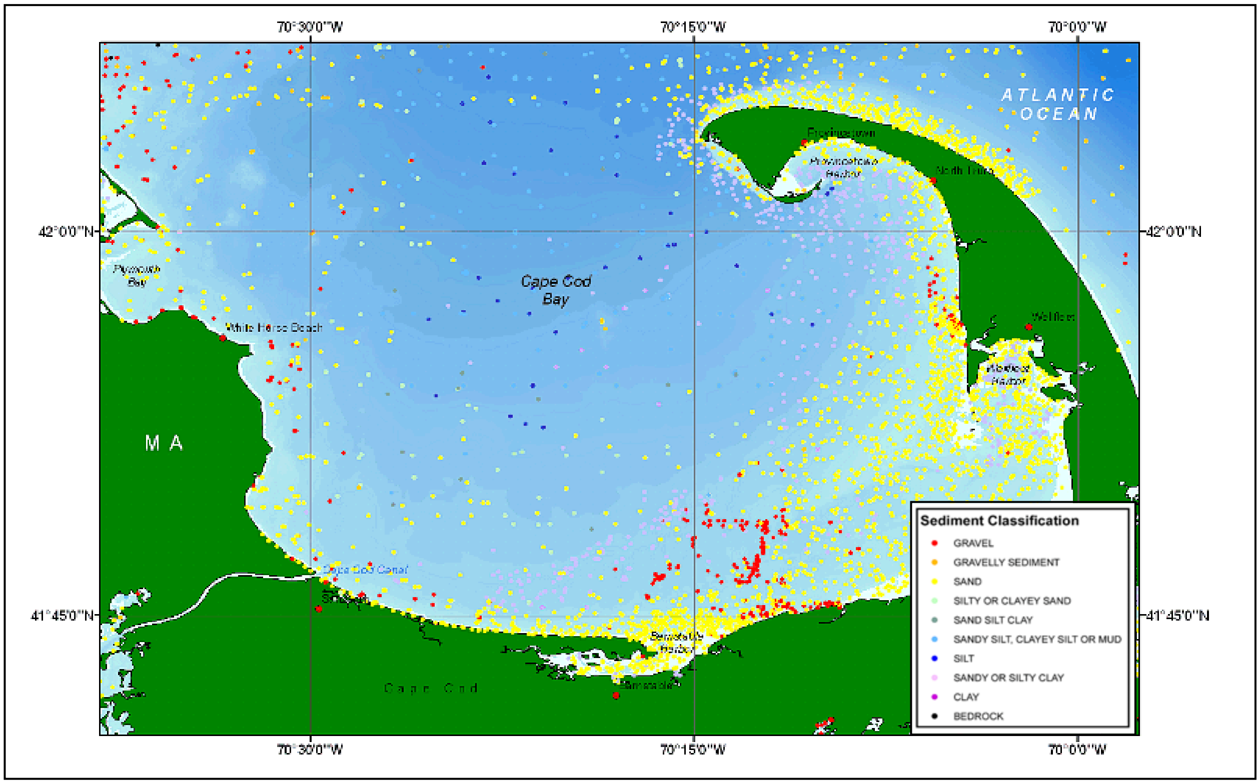

Figure 17. Detailed view of data distribution and sediment classification in the Cape Cod Bay region. Image from USGS Open File Report 03-001 (Poppe and Hasting 2003).

In 2002, the Regional Technical Support Center for GIS at the University of Rhode Island developed a digital map of intertidal estuarine habitats containing grain size and organic content information for intertidal soils in Wellfleet and Hatches Harbors, and Nauset Marsh[37, 142] (Bradley et al. 2002). Site visits were conducted to ground-truth habitat maps delineated from aerial photos and to collect soil samples. The dataset does not contain information about subtidal sediments within CACO's jurisdiction. The products include the final report, a Microsoft Excel® file of sediment characteristics, a shapefile of sediment sampling locations, and orthos and data shapefiles.

<u>Sediment contaminants</u>

Sediment contaminant data for CACO are included in EPA's NCA and NARS (see National and Regional Datasets—Sediment contaminants).

<u>Water chemistry and water quality</u>

Water-chemistry and water-quality data for CACO consist of national/regional datasets (see *National and regional Datasets*).

Submerged habitats and biological communities

Seagrass distribution

The Massachusetts Department of Environmental Protection's Wetlands Conservancy Program (MassDEP-WCP), Massachusetts Office of Coastal Zone Management (MA CZM), and the NOAA Coastal Services Center's Coastal Change Analysis Program (CCAP) developed a baseline digital map of submerged aquatic vegetation (SAV) in coastal Massachusetts from 1993 to 1997[131] (MassDEP and NOAA CSC 1998). The survey utilized protocol developed by CCAP. The data were classified according to the System for Classification of Habitats in Estuarine and Marine Environments (SCHEME) developed in Florida. The program produced six digital coverages of SAV along the entire Massachusetts coast from interpretation of 1:20,000 scale color metric aerial photography collected from 1994 to 1996. Images for the South Coast of Cape Cod were acquired by the James W. Sewall Company in 1994 and 1995 and for the Northern Coast of Cape Cod in 1995 and 1996. MassDEP-WCP delineated SAV polygons and conducted field ground-truthing (videography) to develop signatures and delineate habitats that were not readily apparent in the photography. An assessment of accuracy found that 175 of the 205 sites (85.4%) were mapped correctly.

Seagrass data for CACO (and BOHA) are contained within the MassDEP eelgrass layer published in February 2006 (Figure 18), which constitutes the second statewide SAV datalayer[132] (MassGIS 2010). The MassDEP statewide eelgrass polygons were developed in order to determine change in eelgrass coverage since mapping in the 1990s. Aerial imagery at a scale of 1:12,000 was acquired from 1999 to 2001. The imagery was ortho-rectified at a resolution of 1 m with 90% of the pixels accurate to within 3 m. Photos signatures were interpreted by visual evaluation and polygons were drafted. The minimum mapping unit was 20 m. Field groundtruthing was conducted to verify the photosignatures. The MassDEP eelgrass layer has been updated to include data from 2006/2007 and 2009/2010. Costello and Kenworthy (2011) summarized statewide changes in eelgrass distribution during a 12-year mapping interval. In addition, an online viewer is available for Massachusetts eelgrass maps (MassDEP 2012).

The NPS Northeast Coastal and Barrier Network (NCBN) and USGS supported measurement of eelgrass percent cover and canopy height in upper Pleasant Bay in 2006, 2007, and 2008 (reported in Neckles et al. 2012).

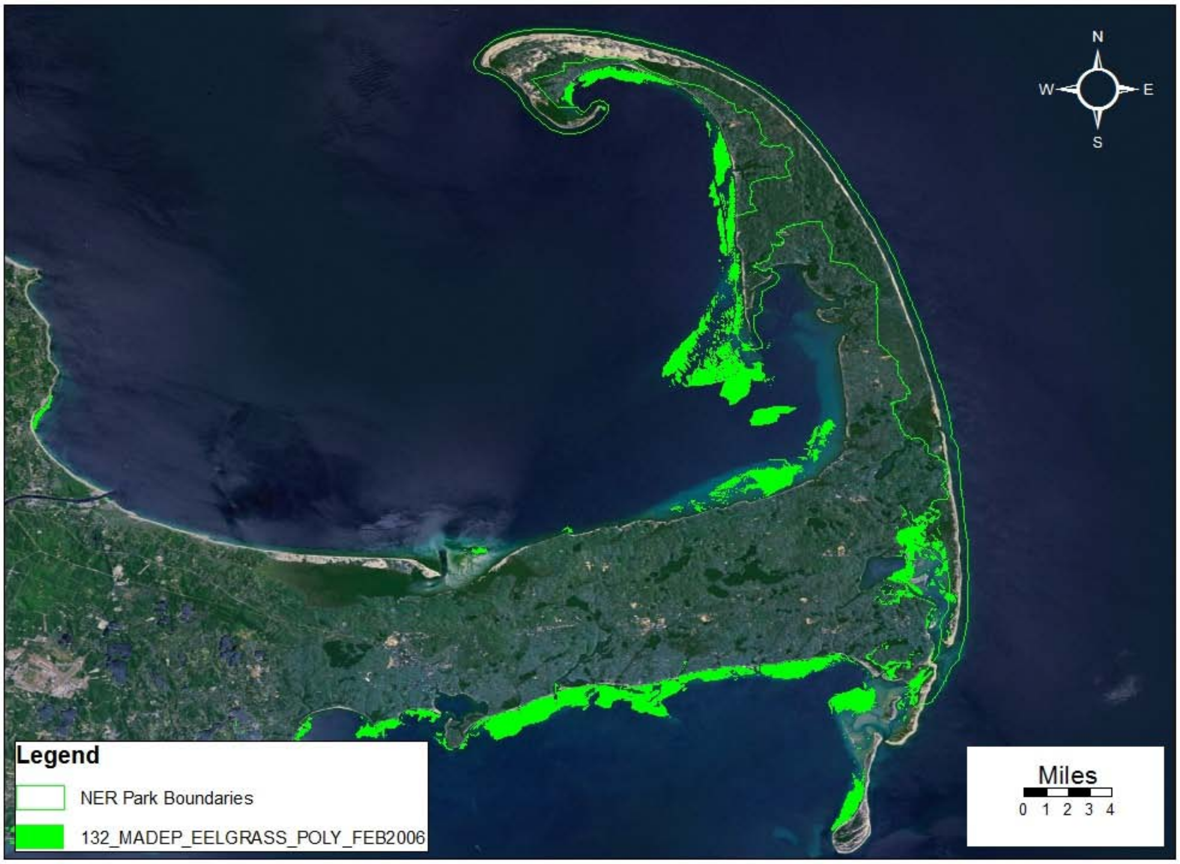

Figure 18. Eelgrass coverage in Cape Cod Bay, 2006. MassDEP (2010).

Biological communities and species inventories

In 2002, the University of Rhode Island developed a digital map of intertidal estuarine habitats based on hydrology, soils, and vegetation in Wellfleet and Hatches Harbors and Nauset Marsh[37, 142] (Bradley et al. 2002). Delineations of these intertidal areas within CACO boundaries were based on 1:20,000 aerial photographs taken in 2000 from MassDEP and contact prints from the Earth Science Information Office at the University of Massachusetts. Site visits were conducted to ground-truth map delineations and to collect soil samples for grain size and organic content analyses (see also *CACO—Sediment grain size and organic content*). Note that the dataset does not contain information about subtidal sediments within CACO's jurisdiction. The products include the final report, a Microsoft Excel® file of sediment characteristics, a shapefile of sediment sampling locations, orthophotographs, and data shapefiles.

A U.S. Fish and Wildlife Service final report (Tiner 2010) includes locations and classifications of wetlands on Cape Cod from the National Wetlands Inventory (see also information on NWI under *National and Regional Datasets*).

In the fall of 2002, MassDEP launched the Wetlands Change Project (WCP), an evaluation of wetland protection efforts in the state over the previous decade via remote sensing and GIS-based data analysis[133] (MassGIS 2011b). This project utilized state wetlands maps produced by MassDEP-WCP over eleven years through interpretation of aerial photography. WCP used the

1:12000 DEP Wetlands datalayer, covering 70% of the state by 2002, to develop a digital database of wetland alterations made from 1990 to 2001. Later aerial imagery was superimposed on base wetland maps to assess changes over time.

Polygons and arcs of wetland environments within Massachusetts have been produced by MassDEP in cooperation with staff from the University of Massachusetts Amherst[141] (MassGIS 2011a). University staff used 1:12,000-scale stereo color-infrared aerial photography, dating from 1990 to 2000, to delineate and classify wetland types. The photo interpretations were field checked by MassDEP-WCP. The interpretations were converted into rectified polygons and lines and merged into a single coverage layer. The resulting layer, DEP Wetlands (1:12,000) - January 2009, is posted on the MassGIS website (MassGIS 2011a). The website notes that because of the scale of the color-infrared photography, these delineations are intended for planning purposes only and should not be used in other processes requiring wetland boundary determination.

The Shellfish Suitability Areas datalayer was developed by MA DMF in collaboration with MA CZM and NOAA CSC[138] (MA DMF, MA CZM, and NOAA CSC 2011). The polygons within this datalayer represent hand-drawn boundaries of locations that are believed to be suitable habitats for 10 shellfish along the Massachusetts coast. The species include the American oyster, bay scallop, blue mussel, European oyster, ocean quahog, quahog, razor clam, sea scallop, soft-shelled clam, and surf clam. The polygons include both current and historic shellfish sites and are based on information from MA DMF, MA shellfish constables, studies of shellfish, and maps. The shellfish suitability areas were not field-checked, nor were boundaries surveyed. The Shellfish Suitability Areas were hand-drawn on DMF Designated Shellfish Growing Areas base maps or NOAA Nautical Charts, digitized, and then converted into an ArcInfo coverage. There is significant overlap of soft-shell, surf clam, and quahog suitable habitats with CACO and smaller areas of overlap with suitable habitats for sea scallop, American oyster, European oyster, ocean quahog, and blue mussel.

The Massachusetts Division of Marine Fisheries (MA DMF) established approximately 2700 sampling stations as of July 2000 as part of the MA DMF Shellfish Project[134] (MA DMF 2000a). Approximately 50 of these sites fall within or overlap the CACO boundary. The stations include sites for collecting water quality, shellfish, and marine biotoxin (PSP) samples, as well as locations of marinas and mooring fields. Each station is associated with a designated shellfish growing area, which is described in a separate datalayer[139] (MA DMF 2000b). The Designated Shellfish Growing Areas datalayer contains areas designated by MA DMF as potential shellfish habitat.

The Massachusetts Division of Fisheries and Wildlife (MA DFW) developed a point coverage layer of all known coastal anadromous fish runs and spawning habitat for three major inland rivers[135] (MA DFW 1997). Interviews with DMF biologists and the best available hydrographic data were used to compile data points onto 1:25,000-scale basemaps. The dataset includes the ANADFISH shapefile and seven related tables stored in ArcSDE. Fifteen datapoints fall within the CACO boundary.

MA DMF compiled the Fish Traps (Weirs) datalayer containing the point locations of fish trap permit holders' traps located throughout the state from 1990 to 1998[136] (MA DMF 1999). Not all locations are currently active. The dataset includes 64 points. One of these points overlaps with CACO boundaries and another five points fall within 2 km of the park.

The Massachusetts Natural Heritage and Endangered Species Program (MA NHESP) database includes the Priority Habitats of Rare Species datalayer, with polygons showing the geographic extent of habitats for state-listed rare species[137] (MA NHESP 2008). The datalayer is based on observations of rare species documented over a 25 year period concluding in 2006. The habitat polygons were heads-up digitized in ArcView at a 1:25,000 scale and referenced to MassGIS 2001 Color Orthophotos. Priority Habitats were digitized by NHESP scientists from documented observations of rare species, their movements, and habitat requirements. Nearly the entire area of CACO is included within the Priority Habitats polygons.

An Environmental Sensitivity Index atlas has been developed for the Massachusetts coastal zone by the NOAA Office of Response and Restoration, NOAA Coastal Services Center, and the Massachusetts Executive Office of Environmental Affairs (MA EOEA)[140] (NOAA 1999). The atlas was developed following the structure and format of ESI's developed for U.S. shorelines (see *National and Regional Datasets*). The ESI atlas for Massachusetts includes digital data, a report, and PDF maps that characterize marine and estuarine environments and wildlife according to their sensitivity to oil spills. NOAA (1999) describes the methods and data sources used to collect comprehensive data on Massachusetts shoreline habitats, sensitive biological resources, and human-use resources.

Assateague Island National Seashore (ASIS)
Maryland's Coastal Atlas—Data website produced by the Maryland Department of Natural Resources (MD DNR) compiles ocean data for the state and is a primary source of geophysical and biological data related to ASIS bay-side and coastal areas (MD DNR 2012a).

<u>Bathymetry</u>
The following data descriptions represent the existing local and park-specific datasets available for ASIS at the time of the inventory's completion, as well as a number of additional bathymetry datasets acquired post-inventory. Descriptions of national and regional datasets relevant to ASIS are included in the *National and Regional Datasets—Bathymetry* section.

The NOAA National Geophysical Data Center (NGDC) developed a 1/3-arc-second (about 10-m) integrated bathymetric and topographic digital elevation model (DEM) for Ocean City, Maryland, as part of the NOAA tsunami inundation modeling project (Grothe et al. 2010; NOAA NGDC 2009). The dataset covers all submerged areas within ASIS. The DEM merges data from various sources dating from 1880 to 2009, including including the NOAA National Ocean Service (NOS), NGDC, U.S. Geological Survey (USGS), U.S. Army Corps of Engineers (USACOE), Federal Emergency Management Agency (FEMA), and other entities. U.S. Army Corps of Engineers surveys have the highest reported horizontal positional accuracy of the compiled bathymetric datasets (2- to 5-m accuracy), yet cover primarily dredged channels. Early NOS hydrographic soundings have positional accuracies of 10s to several 10s of m. Vertical accuracy of the bathymetry measurements are reported as 0.1 m for U.S. Army Corps of Engineers surveys in dredged channels and NOS multibeam surveys (see the following NOS hydrographic survey descriptions below). Vertical accuracies for older NOS hydrographic soundings are several m or up to 5% of water depth.

A number of recent NOAA NOS hydrographic surveys pertain to ASIS[1] (Figure 19). Conducted in 2008, survey H11872 provides high-resolution multibeam coverage along the northernmost section of the park in ocean areas deeper than about 3 m (referenced to MLW; NOAA NOS 2008b). Survey coverage totaled about 263 km^2 including areas around the Ocean City Inlet and the shoal nearest the inlet (Figure 19). The depth range was 2.95 m (0.270-m uncertainty) to 24.82 m (0.270-m uncertainty; Davis 2009). Multibeam surveying was conducted with a Reson SeaBat 8101 echosounder operating at 240 kHz. Swath width was 3.5 times water depth. Tracklines were spaced 40 m apart; cross lines were spaced 780 m apart. Full multibeam coverage was achieved in depths greater than 13.5 m. Products include 13 Bathymetry Attributed Grid (BAG) files, each containing a gridded bathymetric surface, depth data, uncertainty values, metadata, and authentication information. This survey also included sidescan surveying, bottom sampling, and sub-bottom profiling (see *ASIS—Acoustic seabed characterization* and *Hydrogeologic framework*).

Also conducted in 2008, NOS hydrographic survey H11874 covered about 248 km^2 of ocean area on the east side of Assateague Island, abutting and directly south of survey H11872 (Figure 19). The survey included multibeam and sidescan sonar, sub-bottom profiling, and bottom sampling in depths ranging from 3.93 m (0.270-m uncertainty) to 22.84 m (0.280-m uncertainty) (Smith 2009). The instrumentation, trackline spacing, swath width, percent coverage, and products are identical to those described in survey H11872 (see also *ASIS—Acoustic seabed characterization* and *Hydrogeologic framework*).

Combined, surveys H11872 and H11874 span approximately half of the shoreface length of ASIS. Older hydrographic survey coverage from the 1930s to 1980s is available on the NOAA NGDC website for the remaining half of the oceanside portions of the park, as well as other portions of the park. Among these historical surveys is a geodatabase raster dataset of bathymetry off the coast of Assateague Island, including MD and VA, collected from 1977 to 1979[251] (NOAA NGDC date unknown-b), and survey data from survey H09764 collected in 1978 off the coast of Ocean City[252] (NOAA NGDC date unknown-a).

In 2010, ASIS produced and published a Maryland/Virginia Coastal Bays Bathymetry Map based on hydrographic data collected by the Maryland Geological Survey (MGS) in Maryland between 2000 and 2003 and in Virginia in 2007[247] (ASIS 2010a). The map is part of a larger document containing information about surficial sediments in Maryland and Virginia Coastal Bays (see *ASIS—Grain size and organic content* and *Sediment sontaminants*). The surveys from each state are described below.

An interpolated 10-m resolution bathymetry grid of navigable waters (greater than 2 m) in Maryland's Coastal Bays is based on individual echosounder soundings from hydrographic surveys conducted in 2000 and 2003 by the Maryland Geological Survey[6, 7] (Author unknown 2006). The project was funded by the Maryland Department of Natural Resources and NOAA Coastal Services Center. This dataset includes interpolated bathymetry only for the bayside portions of ASIS, not for the oceanside submerged lands contained along the park's eastern boundary. Out of the 548,593 soundings taken during the survey, 68,605 are within ASIS boundaries. Bathymetric data were collected using a Precision GPS and a Knudsen 320B/P dual frequency echosounder with sounding frequencies of 200 and 28 KHz. Depth soundings were taken approximately every 1 m along east to west track lines spaced 400 m apart and along north to south track lines spaced 1000 m apart. Final reports on these surveys were published in 2001 and 2004 (Wells and Ortt 2001; Kerhin et al. 1999). The project metadata contain references to ASIS shoreline data and additional bathymetric metadata (ASIS 2000).

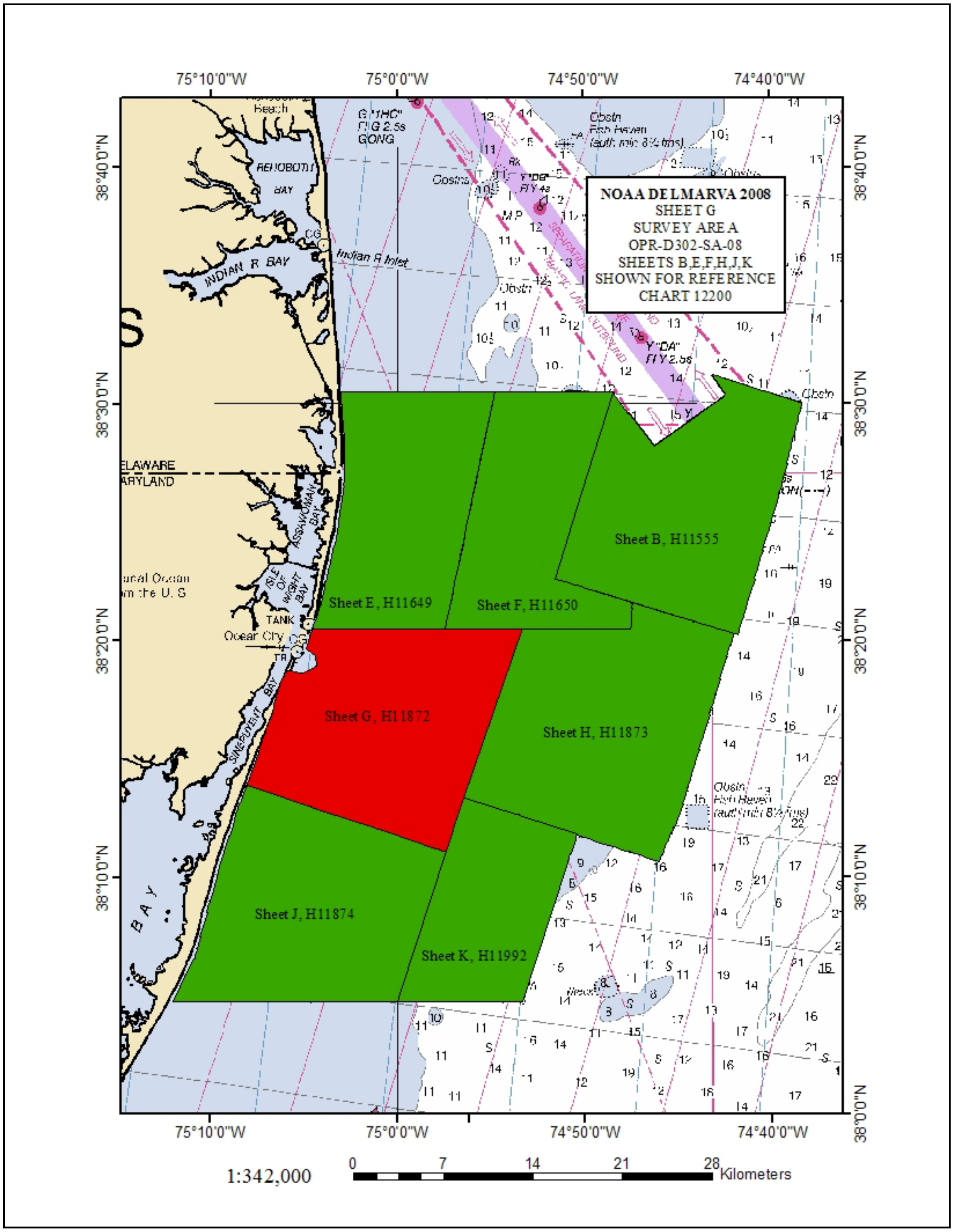

Figure 19. NOS hydrographic surveys in the vicinity of ASIS in 2008. Image from Smith (2009).

An older dataset from 1964-1966 provides contours and point coverage bathymetry for the Maryland portion of Assateague's coastal bays [8, 9] (no citation in metadata). Thirty of the survey's 381 points fall within the ASIS boundary.

The Maryland Geological Survey, MD DNR, and NPS conducted bathymetric hydrographic surveys in navigable portions of the Virginia section of Chincoteague Bay in 2007, as part of a larger subaqueous sediment sampling project for the Virginia Coastal Bays[240] (Wells et al. 2009; see also *ASIS Grain size and organic content* and *Sediment contaminants*). The survey was conducted to develop a bathymetric dataset that matched existing 2003 bathymetry data collected by the Maryland Geological Survey for the Maryland Coastal Bays (*see records 6 and 7*). Survey transects were 400 m apart, with cross line surveys spaced 2000 m apart. A total of approximately 400 km of track lines were collected using a dual-frequency (200 KHz and 28 KHz) echosounder in waters greater than 0.5-m depths. Horizontal accuracy of the data is estimated at 3 m and vertical accuracy is estimated at 0.4 m. An interpolated grid of the bathymetry data was developed in geodatabase raster database format[240] (ASIS 2008).

USGS Open-File Report 2007-1176 presents a dataset of 58 bare earth 3-m resolution topography maps and GIS files derived specifically for ASIS and mapped exclusively within the ASIS boundary[239] (Brock et al. 2007a, b). Based on NASA Experimental Advanced Airborne Research lidar (EAARL) surveys, the dataset includes high-resolution (vertical resolution +/- 20 cm) submarine topography for only the very shallowest areas of the park (i.e., to -1 NAV88 Elevations).

The NOAA Coastal Services Center published coastal topographic and bathymetric lidar survey data collected along the New York, New Jersey, Maryland, and Virginia coastline as part of the National Coastal Mapping Program (NOAA CSC 2006; see *National and Regional Datasets—Bathymetry*). The survey footprint and metadata can be viewed on the NOAA CSC Digital Coast Data Access Viewer (NOAA CSC 2012).

Bathymetry and elevation profile surveys of the Ocean City Tidal Inlet were conducted by the U.S. Army Corps of Engineers, in cooperation with ASIS, NPS, and state and local partners, as part of a beach restoration program targeting the northern 10 km of ASIS[10]. Described in the NPS 2003 Natural Resource Year-in-Review[57] (Blumberg 2004), the North End Restoration Project was designed to mitigate the effects of the Ocean City Inlet jetty system, which was built in the 1930s to stabilize an inlet created by a hurricane. The jetties prevented natural sand migration along the shore and deprived the northern portion of ASIS of sand. Aerial photos from 1933 to 2000 and a digitized polygon of the Ocean City Inlet and jetty system visually represent changes over this time period[66,67] (Bass et al. 2004). To restore the island's natural sand budget and enable sand replenishment (i.e., overwash) during storm events, sand was dredged from a shoal about 6 km offshore and deposited in the surf zone at the north end of ASIS (see Rodriguez 2006b,c[58] for locations). The full course of the project involved an initial feasibility study beginning in the 1990s, sediment dredging and deposition of dredged material in the nearshore of northern Assateague Island beginning in 2003, and associated ongoing monitoring and impact assessments (Rodriguez 2006a; 2011a). The U.S. Army Corps of Engineers performed two dredging events per year from 2004-2006[58] (Schupp et al. 2007). The partners collected a variety of bathymetrical data as part of the project through: (1) annual hydrographic surveys of the inlet system; (2) annual elevation profile surveys along the northern 13 km of the island from 2003-

2007; (3) before and after multibeam sonar bathymetry surveys of the areas to be mined or dredged; (4) annual lidar surveys of the north end beginning in 1997 (ASIS 2011b); and (5) additional EAARL lidar surveys since 2002 (Rodriguez 2006a; ASIS 2011a).

Beach and nearshore profile surveys associated with the project were conducted to monitor bathymetric and volumetric changes occurring as a result of the mechanical sediment by-passing events. In 2003-2005 and 2007, the partners collected elevations during sled surveys conducted from the upper beach to the depth of closure (where waves do not normally move sand) along 29 transects spaced at 0.25-km intervals[59] (Rodriguez 2003-2007; Offshore and Coastal Technologies 2007). The profiles extended to water depths of about 8 m and occurred from the Ocean City Inlet south along the northernmost 13 km of the island. Available as shapefiles, the profile data have 0.03-m horizontal accuracy and 0.015-m vertical accuracy. Beach profile surveys out to closure depth were also conducted in 2003 along about 12,000 m of shoreline from the inlet southward to assess the results of a constructed berm on northern ASIS[57] (Offshore and Coastal Technologies 2003). Nearshore bathymetry derived from these surveys may be compared to earlier profiling conducted by the U.S. Army Corps of Engineers in the 1990s along 19 profiles to evaluate the success of a jetty rehabilitation project in preventing shoaling within the Ocean City Inlet and facilitating sand accretion at ASIS[66, 67] (Bass et al. 1994). Shoreline change maps were combined with periodic bathymetric survey data and aerial photography to determine the effects of the rehabilitation project and the profile response (Rodriguez date unknown). Additional information about beach profiling and shoreline change assessment is available in the *ASIS—Hydrogeologic framework* section.

A series of bathymetry surveys were also conducted as part of a 2002 rehabilitation of the south jetty. In 2000, the U.S. Army Corps of Engineers Baltimore District performed a pre-rehabilitation bathymetry survey with a conventional single-beam system (Buttolph et al. 2006). In 2004 and 2005, comprehensive post-rehabilitation multibeam swath bathymetry surveys of the entire ebb shoal were performed encompassing submerged bayside, oceanside, and inlet areas at the very northern end of ASIS (Figure 20, Figure 21; Buttolph et al. 2006). In addition to these comprehensive multibeam surveys, nine partial-area multibeam surveys were conducted within the Ocean City Inlet, navigation channels, and associated tidal deltas over a three year period from 2004 to 2006 (ASIS 2011a). Together these surveys represent modern, high-resolution surveys for the northernmost section of ASIS that enabled bathymetry change analysis within this time period. The average resolution of the comprehensive and partial multibeam surveys is +/- 0.037 m. The multibeam data are reported to be about 15 times denser than the single-beam survey data, achieve higher resolution, and provide 100% coverage of the seafloor over a ribbon as wide as four times water depth along the track line.

Krantz (2009) created lidar DEMs with a 10-cm contour interval for all of ASIS based on EAARL lidar survey collected by NASA in 2002. A 1985 EPA report on the potential implications of sea-level rise for beach erosion control efforts in Ocean City, Maryland presents bathymetry contours to 9-m depths for 1929, 1965, 1978, and 1979, as well as shoreline position data from 1850 to 1980[70] (Titus et al. 1985).

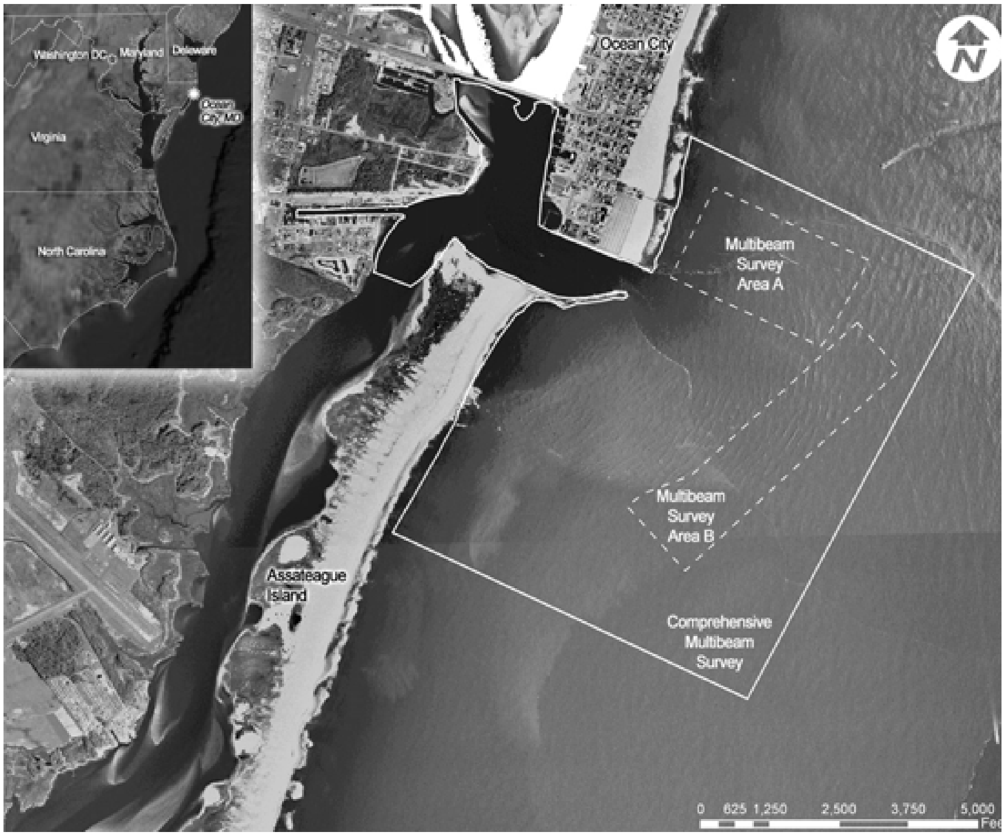

Figure 20. Boundaries of multi-beam surveys performed since 2003 from Buttolph et al. (2006).

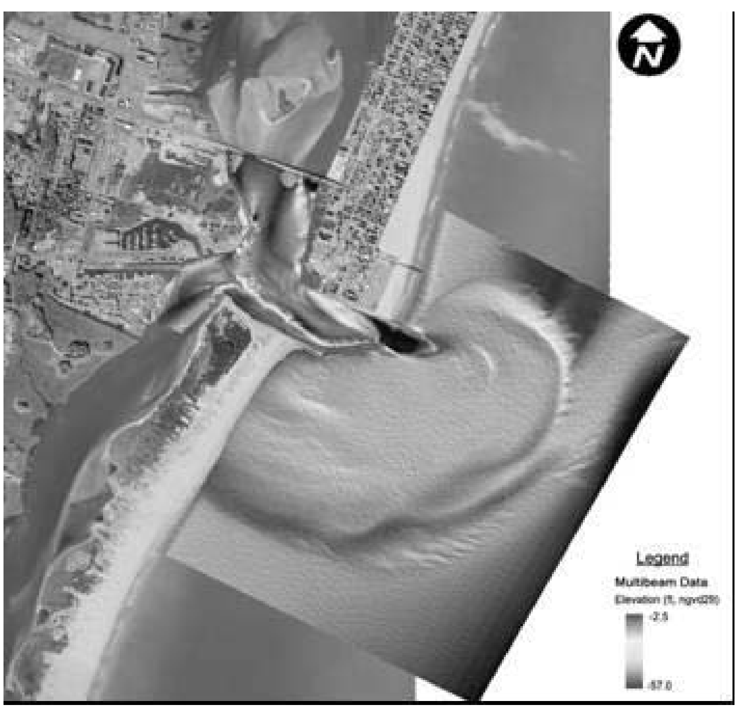

Figure 21. Comprehensive multibeam survey of Ocean City Inlet and ebb shoal, August 2005 (Buttolph et al. 2006).

In 1994 to 1995, bathymetry of a shoal field located 1.4 km offshore of Assateague Island was measured by the Maryland Geological Survey as part of an effort to assess offshore sand resources[47] (Conkwright and Gast 1995). Seismic data were used to map the shoal field's bathymetry, as well as stratigraphy and sub-bottom structures (see also *ASIS—Hydrogeologic framework*). More than 185 km of seismic lines were recorded using a Datasonics acoustic profiling system operating at 3.5 kHz. Bathymetric and sub-bottom reflectors were digitized along each trackline to produce three-dimensional profiles of the bottom and sub-bottom. The data were overlain on a NOS bathymetric model of the Delmarva Atlantic shelf. Products include five and ten ft bathymetry contour maps of the shoal fields.

Hydrography

The Environmental Sensitivity Index (ESI) for Virginia contains a datalayer on Virginia's coastal hydrography (Research Planning Inc. 2005); see *ASIS—National and Regional Datasets* and *Biological communities and species inventories*). The HYDRO datalayer contains data organized by geographic, socioeconomic, and water features. The data range from 1998 to 2004. This dataset is part of a larger ESI dataset characterizing Virginia's marine and coastal environments and wildlife according to their sensitivity to spilled oil. Data sources used in this dataset are described within the metadata.

Wave height, direction, and periodicity

Data on wave climate in the vicinity of ASIS are collected at two locations, although neither is in close proximity to the park (Table 8, Figure 22, NOAA NWS 2012b). Buoy 44009 (LLNR 168) is located approximately 50 km southeast of Cape May, New Jersey and approximately 75 km from Ocean City Inlet (Figure 22). Off Cape Henry, Virginia, at the mouth of Chesapeake Bay and about 100 km south-southwest of the park, are Buoy 44099 operated by the Scripps Institution of Oceanography Coastal Data Information Program and Station CHLV2 (Chesapeake Light) operated by the NDBC (Table 8).

Tide range, phase, and currents

Real-time tide data in proximity to ASIS are collected at a number of locations (Table 8). NOAA Station 8570283 is located at Ocean City inlet and is therefore particularly relevant to the park (Figure 22, NOAA NOS 2011). The other NOAA stations are farther away: 8631044 is in Wachapreague, Virginia, about 40 km south of the southern end of the park within the Burtons Bay system, and 8557380 is in Lewes, Delaware about 55 km north of the northern end of the park (NOAA NOS 2011). Similarly, both of the USGS stations are located within Delaware's coastal bay and have limited relationship to conditions at ASIS (Figure 22). MD DNR maintains a continous water-level monitor in Chincoteague Bay (Figure 22, Table 8; MD DNR 2012b).

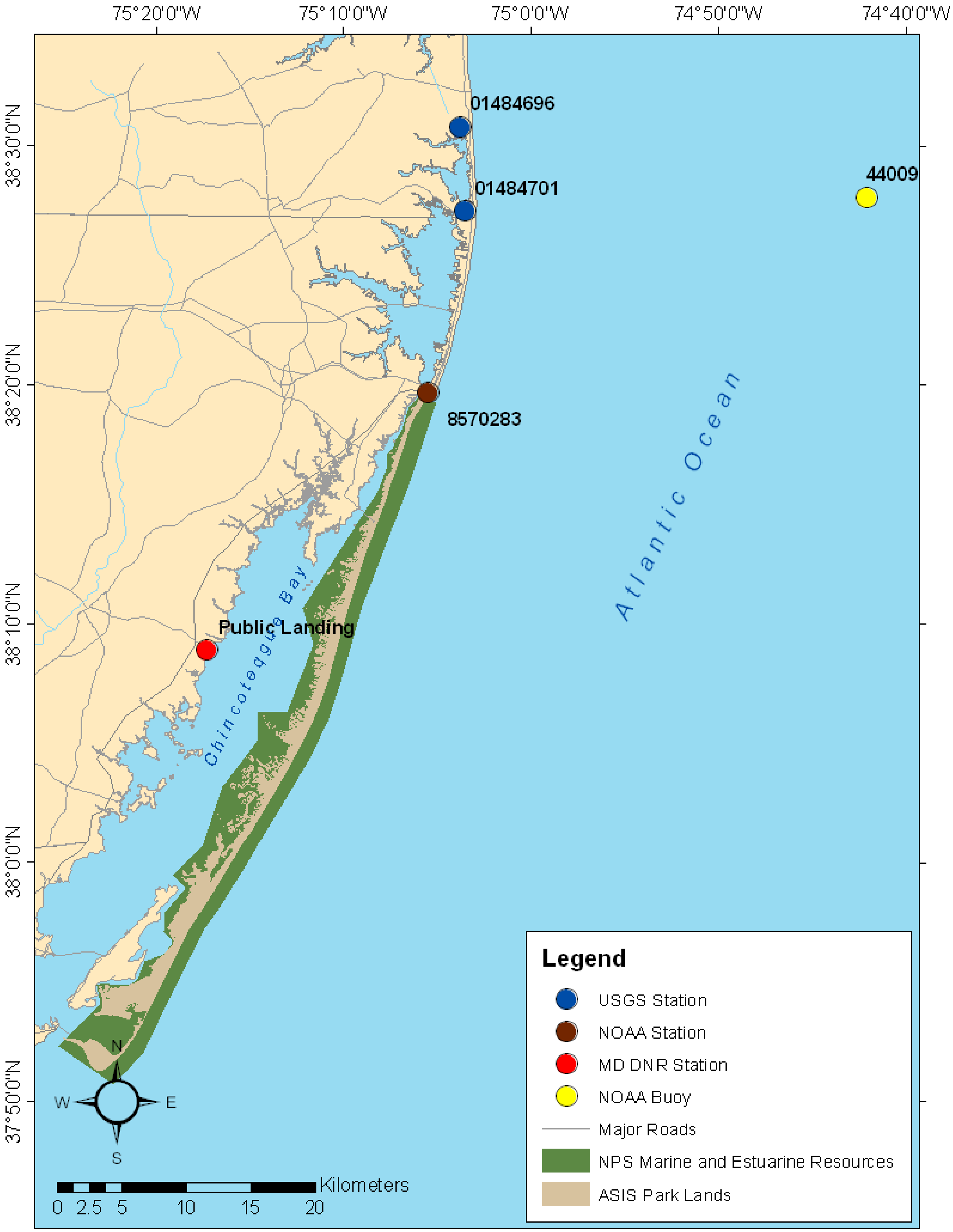

Figure 22. NOAA and USGS hydrographic data stations in the vicinity of Assateague Island National Seashore (MD DNR 2012b, NOAA NOS 2011, NOAA NWS 2012b, USGS 2012b).

Table 8. Hydrographic monitoring stations in the vicinity of Assateague Island National Seashore (MD DNR 2012b, NOAA NOS 2011, NOAA NWS 2012b, USGS 2012b).

ASIS	NOAA NDBC Station	NOAA NDBC Buoy	SCRIPPS Buoy	NOAA NOS Stations		NOAA PORTS Station	USGS Stations		MD DNR Station
Station Name	**CHLV2**	**LLNR 168**		**OCIM2**	**WAHV2**				**Public Landing**
Station Code		**44009**	**44099**	**8570283**	**8631044**	**8557380**	**01484701**	**01484696**	
Wind Direction	+	+	-	+	+	+	-	-	-
Wind Speed	+	+	-	+	+	+	-	-	-
Wind Gust	+	+	-	+	+	+	-	-	-
Wave Height	-	+	+	-	-	-	-	-	-
Dominant Wave Period	-	+	+	-	-	-	-	-	-
Average Period	-	+	+	-	-	-	-	-	-
Mean Wave Direction	-	-	+	-	-	-	-	-	-
Atmospheric Pressure	+	+	-	+	+	+	-	-	-
Pressure Tendency	+	+	-	-	-	-	-	-	-
Air Temperature	+	+	-	+	+	+	-	-	-
Water Temperature	-	+	+	+	+	+	-	-	+
Dew Point	+	-	-	-	-	-	-	-	-
Water Level	-	-	-	+	+	+	+	+	+
Conductivity/Salinity	-	-	-	-	-	-	-	-	+

Hydrogeologic framework

A geologic overview of ASIS is provided in Schupp (2006). The document describes the park's physical setting, geologic formation, sediments, groundwater resources, physical and storm processes, and inlets. The report also provides a description of the North End Restoration Project and the creation and maintenance of the Ocean City Inlet jetty system (see below and *ASIS—Bathymetry*).

The NPS Geologic Resources Inventory (GRI) Scoping Report for ASIS provides a list of general geologic maps covering parts of the ASIS quadrangles (Thornberry-Ehrlich 2005a; see *National and regional Datasets—Hydrogeologic framework*). Scoping meeting participants identified many maps produced by USGS and state agencies (Maryland Geological Survey, Delaware Geological Survey, Virginia Division of Mineral Resources) that provide coverage of geology, shoreline change, hazards, minerals, surficial- and hydro-geology, and stratigraphy for parts of ASIS. However, participants agreed that traditional geologic maps are not adequate for geologic resource management in the dynamic coastal environment. Therefore, the hydrogeomorphic maps produced by the NPS GRI for ASIS subdivide and categorize the island surface in terms of its geomorphology as related to characteristics of the ground-water hydrology (Krantz 2010). The conceptual framework of the map is based on the large-scale geomorphology of the island. This is combined with data from extensive geophysical surveys (using ground penetrating radar, electrical resistivity, and borehole geophysical tools) and groundtruthing observations. Primary map units (island core, overwash, tidal marsh, former inlets, washaround, ponds) are defined based on consistent geomorphic and hydrologic character, and map subunits define gradients of hydrologic conditions within the primary map units.

Surface and groundwater pathways

In addition to localized sources below, data on surface-water level, stream flow, and groundwater level are provided by the USGS National Water Information System (USGS 2012b, see *National and Regional Datasets—Hydrogeologic framework*).

Dillow et al. (2002) reported results of a collaborative study between USGS and ASIS to describe groundwater flow paths that carry freshwater to the coastal bays and their tributary streams adjacent to the seashore, and to analyze nutrient concentrations associated with these freshwater inputs. The study area consisted of Chincoteague, Newport, and Sinepuxent Bays, their combined watersheds, and Assateague barrier island.

Bedrock geology and shallow stratigraphy

Two of the bedrock geology and shallow stratigraphy records within the inventory occurred in the 2000s, while the rest date back to the early 1990s. Included in the more recent studies, Thornberry-Ehrlich[49] (2005a) contains a general description of ASIS stratigraphy as part of an effort to identify geologic resource management issues pertaining to the park. Additionally, Krantz and Levin (2005) describe seismic track line surveys that were conducted as part of the Assateague Island Geologic Investigation[5]. The seismic data were used in conjunction with sidescan sonar data to develop projected images of the seafloor and interpret surficial stratigraphy to 30-m depths along the tidal channel, flood-tidal delta, and eastward/offshore of the park. The study area covered the nearshore shoreface of southern ASIS (the Virginia section). A set of 28 PDF plates was developed that depict seismic and sidescan sonar lines (see also *ASIS—Acoustic seabed characterization*).

A number of other studies conducted by the Maryland Geological Survey took place in the 1980s and 1990s. Beginning in 1992, the Maryland Geological Survey, Delaware Geological Survey, and the U.S. Minerals Management Service conducted a 5-year Offshore Sand Resources Study to assess the quality and quantity of offshore sand deposits for potential beach nourishment resources offshore of the ASIS seaside boundary (Conkwright 2011). The cooperative mapped the volume and grain size of offshore shoals and developed a three-dimensional shoal model to aid estimations of sand volume and variability. Seismic profiling surveys were conducted at 19 shoals to determine internal shoal structure. These data were supplemented with more than 1,500 km of seismic profile data collected from 1985 to 1995 by the U.S. Minerals and Management Service and the U.S. Army Corps of Engineers. Sediment types were interpreted through stratigraphic analysis of seismic data and corresponding core sample ground-truth data (see also *ASIS—Grain size and organic content*). The seismic data were digitized and combined with a bathymetric surface map based on NOAA NOS hydrographic survey data.

Eight of the 19 shoals that were assessed via 3-D modeling in the Offshore Sand Resources Study were selected by the Maryland Geological Survey for further study in 1994 to 1995[47] (Conkwright and Gast 1995). These shoals begin approximately 1.4 km from Assateague Island and extend eastward 23 km. Over 185 km of high-resolution seismic survey data and existing vibracore samples were used to estimate the quality and quantity of sediments contained within the shoals. Seismic profile data were collected with a Datasonics acoustic profiling system operating at 3.5 kHz. Ground-truth data consisted of 56 cores collected during the project, and more than 200 archival cores containing more than 3,000 sediment samples from MMS and U.S. Army Corps of Engineers projects. Seismic profiles and vibracore ground-truth data were used to interpret shoal stratigraphy, sub-bottom structures, textural parameters, and volume (See also *ASIS—Grain size and organic content*).

In 1993 and 1996, the Maryland Geological Survey conducted similar sand resources studies on another shoal field, which extends from 6.4 km to 19.3 km offshore of Assateague Island. In the 1993 study, seismic profiling and archival vibracore data were used to assess the sand resources on the shoal field[48] (Conkwright and Gast 1994). Because archival vibracore sedimentologic data were insufficient to characterize sand quality and quantity accurately, a second vibracore sampling study was conducted in 1995 on five shoals within the shoal field[48] (Conkwright and Williams 1996). Samples were classified for their sand resource potential based on grain size, sorting, and depth. The volume of sand was calculated for each resource classification.

In addition to these studies, two reports describe the shallow geologic framework of the continental margin off Ocean City, Maryland (Wells 1994; Kerhin et al. 1999). The Maryland Geological Survey examined over 300 km of high resolution seismic profile records, lithological logs, and textural data to delineate the shallow geologic framework of Maryland’s inner continental shelf[46]. The seismic profiles and vibracores were collected by the U.S. Army Corps of Engineers as part of a project initiated in the mid-1980s to rebuild 12 km of beach in Ocean City. Seismic reflection profiles were obtained in 1986 and vibracores were conducted between 1986 and 1989. This 1994 report expands upon original analysis of sand deposit extent and thickness in order to delineate shallow stratigraphy and map sediment textural trends. The report also builds upon former studies conducted by the Maryland Geological Survey as part of the first four years of the Minerals Management Continental Margin Program (Kerhin 1989; Kerhin and Williams 1987; Toscano et al. 1989; Toscano and Kerhin 1990; Toscano and York 1992). The data extends from the Ocean City Inlet to the Maryland/Delaware line and from the shoreline to 5.6 km offshore. Although most of the dataset lies north of ASIS, the dataset overlaps the park boundary where the boundary extends about 250 m into the Ocean City Inlet.

As part of the Maryland Coastal Bays Sediment Mapping Project, the Maryland Geological Survey conducted shallow seismic profile surveys over about 33 km of Chincoteague and Sinepuxent Bays in 1992[32,33] (Wells and Conkwright 1999). Seismic profiles were collected using a Raytheon subbottom profiler and fathometer (Model DE 719). Maximum penetration of the 7.0-kHz signal was between 6 to 7.5 m. Shallow water depths and hard bottom resulted in obscured detail in the seismic records. A final database and synthesis report was submitted to the Coastal Zone Management Program of the Maryland Department of Natural Resources.

In addition to records contained in the inventory, sub-bottom profiling was conducted by NOAA NOS in 2008 as part of hydrographic survey H11872 (NOAA NOS 2008b) and survey H11874 (Smith 2009) using a Brooke Ocean Technology Moving Vessel Profiler and Seabird Seacat SBE 19 CTD Profiler. Combined, surveys H11872 and H11874 span approximately half of the shoreface length of ASIS (see also *ASIS—Bathymetry and Acoustic seabed characterization*).

Historical shorelines, shoreline position, and beach elevation profiles
Much of the beach and shoreline profile data available for ASIS are related to the North End Restoration Project and closely linked to several nearshore bathymetric measurements (see description in *ASIS—Bathymetry*).

The focus of several North End beach profile and shoreline surveys is a berm constructed by the U.S. Army Corps of Engineers in 1998 to reduce the threat of island breaching in areas deprived of sediment by the Ocean City Inlet jetty system. The berm was reconfigured in 2002 and 2005 to facilitate natural overwash during storm events. An article on the effects of this constructed berm on ASIS geology and habitat is included within a review of National Park Service efforts in 2004[55] (Schupp 2005b). Related datasets include 26 beach profile surveys conducted in 2003 after the first berm reconfiguration along about 12,000 m of shoreline[57] (Offshore and Coastal Technologies 2003) and surface elevation surveys conducted monthly from 2004-2006 before and after the second alteration[56] (Rodriguez 2005; Schupp and Rodriguez 2005). Each monthly survey collected over 3000 elevation and location points every 2 to 4 m with a Trimble 5700 total station, with a horizontal and vertical accuracy of less than 0.15 m. Shapefiles, metadata, photographs, aerial photos, CAD files, and reports were produced in association with the reconfiguration events. Associated mapping of overwash sites and monitoring of shoreline changes and overwash events occurred from 2004 to 2006 (ASIS 2004[50], 2006b[51], c[52], d[53]). ASIS determined horizontal and/or vertical positions of the overwash sites using a Trimble ProXR GPS or Trimble 5700 RTK GPS. Horizontal accuracy of the 2004 data is 0.3 m (68%). The 2006 surveys collected both horizontal position and vertical elevation data, achieving less than 0.15 m horizontal accuracy and less than 0.20 m vertical accuracy. The datasets are completely within the ASIS boundary.

ASIS also collected beach profile elevation and shoreline position data on a biannual basis from 1995 to 2004 as part of a long-term geomorphological monitoring program to evaluate trends in island topography and storm-driven changes. GPS baseline monuments were established in 1993 to provide horizontal and vertical controls for data collection[65]. Data collection varied by year, but included topographic profiles, shoreline positions, lidar, and aerial photography. Reports documenting the methods and results of this program were published for surveys from 1999 to 2004[60] (Schupp 2004 and 2005a; O'Connell 2001-2003; Reiner 2000). The following datasets were produced as a part of this monitoring program:

1. Topographic profile shapefiles for 2004 to 2007 were developed from cross-island elevation surveys conducted with a Trimble 5700 GPS total station. Elevations were recorded at significant changes in topography and at about 10-m intervals along 22 profile transect lines spaced 1-2 km apart along the Maryland portion of the island[64] (Rodriguez 2004-2006; Rodriguez 2007). Each transect spanned from wading depth oceanside to wading depth bayside.
2. Shoreline positions were documented on a quarterly basis from 1994 to 2006 using a Trimble ProXR GPS to evaluate shoreline stability and change[61] (ASIS 2007). Some surveys focused on ocean shorelines in Maryland and Virginia portions of ASIS, others also included inlet and bay shorelines. Horizontal precision is reported as sub-meter.
3. Lidar (1-m-horizontal and 15-cm-vertical resolution) was processed into 3-D GIS layers, georeferenced aerial photography, and special profile transects to document storm-specific effects or to support lidar ground-truthing. The survey data are archived in the NPS Electronic Library.

Historical shoreline vector data for ASIS are available for multiple years between 1850 and 2002 from known and unknown sources[62]. These data include shoreline location information digitized from aerial photography and a vector dataset that contains ocean and bay shorelines of the Maryland and Virginia portions of ASIS. The data are clipped from shoreline vector data from Maryland, Virginia, and Delaware coastal bays, which were digitized from aerial photography taken from 1989 to 2003[63]. Data sources include the Maryland Department of Natural Resources, the Virginia Institute of Marine Science (VIMS), and USGS. Metadata for these shoreline vectors are available online (VIMS 2011; MGS 2003).

A series of eight published articles and reports relate to coastal sediment processes on ASIS and other barrier island systems. One is a numerical model that simulates the effects of dune overwash on sediment transport and dune profiles[54] (Larson et al. 2004). The model was validated using overwash datasets from Ocean City and ASIS. Other articles include the effects of overwash on dunes at the North End of Assateague Island (Fisher and Stauble 1978); the results of mapping morphological responses to a specific 1962 storm along the middle Atlantic coast (Morton et al. 2003); a technical note summarizing regional coastal and inlet sediment transport processes that may influence engineering projects (Larson et al. 2002); the effects of erosion on vegetation patterns along the northern end of ASIS (Roman and Nordstrom 1988); a sediment budget analysis system applied to estimate volume, erosion, and deposition rates in the Ocean City Inlet (Rosati 2005); and two reports on shoreline erosion as a source of sediments and nutrients into Maryland Coastal Bays (Wells et al. 2002, 2003). In addition, ASIS and a Science Advisory Panel for the ASIS Division of Natural Resource Management produced a series of documents and standard operating procedures dating from 1992 to 1995 related to dune management, beach grass planting, and dune fencing[68] (Railey and Furbish 1995). No GIS data are associated with these documents.

In 2004, USGS partnered with the NPS Geologic Resources Division to develop a Coastal Vulnerability Assessment of ASIS[69] (Pendleton et al. 2004). The assessment used a coastal vulnerability index (CVI) to map the relative vulnerability of the coast to future sea-levelrise. Sources of data are listed within a table (p. 20) and include Maryland Geological Survey shoreline data from 1843 to 1994, a NOAA NGDC Coastal Relief model, orthophotos, and various NOAA resources. In 2006, ASIS produced a map incorporating sea-levelrise predictions for the year 2100 for the Virginia section of ASIS (ASIS 2006e). The map utilizes ASIS elevation data obtained by lidar in 2004 and aerial photographs taken in October 2003.

Surficial geology

Acoustic seabed characterization

Sidescan sonar surveys were conducted simultaneously with seismic track lines as part of an Assateague Island Geologic Investigation in 2005[5] (Krantz and Levin 2005; see also *ASIS—Hydrogeologic framework*). Sidescan data were used to develop projected images of the seafloor and interpret surficial stratigraphy along the tidal channel, flood-tidal delta, and eastward/offshore from the southern extent of the park. The study area covers the nearshore Atlantic shoreface area of southern Assateague Island (the Virginia section). Associated ground-truthing is not documented.

In 2008, NOAA NOS conducted sidescan surveys and groundtruth bottom sampling in an area southeast of Ocean City as part of survey H11872 (NOAA NOS 2008b; Davis 2009; see also *ASIS—Bathymetry* and *Hydrogeologic framework*). Klein 3000 towed sidescan surveys were conducted within all parts of the study area except the area around the Ocean City Inlet and the shoal east and south of the inlet; these areas were surveyed with multibeam only. The depth range of the sidescan survey was from 2.95 m (0.270-m uncertainty) to 24.82 m (0.270-m uncertainty). Also conducted in 2008 were sidescan sonar surveys and bottom sampling as part of NOAA NOS survey H11874 (Smith 2009). The study area abuts the southern boundary of survey H11872 and includes depth ranges from 3.93 m (0.270-m uncertainty) and 22.84 m (0.280-m uncertainty). The survey operations were conducted at a consistent 40-meter line spacing chosen to achieve 200% sidescan sonar coverage. Combined, surveys H11872 and H11874 span approximately half of the shoreface length of ASIS. The backscatter intensity data collected through these surveys was used primarily for object detection (i.e., navigational hazards). Interpretive maps of surficial sediment distribution were not produced from these data.

Sediment grain size and organic content

Sediment grain size and organic content data for ASIS consists of regional datasets such as EPA's NCA and NARS, CONMAP, usSEABED, the USGS Marine Aggregate Resources Project, and the East Coast Sediment Texture Database (see *National and Regional Datasets—Sediment grain size and organic content*), as well as the following localized sources.

In 1993, grain size analyses were conducted in the bays bordering ASIS as part of a larger Coastal Bays Joint Assessment to assess the ecological condition of the Delaware and Maryland coastal bays (Kutz 1999a). Sixty-eight sampling stations were established in Assawoman and Chincoteague Bays bordering ASIS; approximately six of the points fall within or overlap the ASIS boundary. At each station, grab samples from the top 2 to 10 cm of the seafloor surface were collected and analyzed for grain size, as well as other parameters such as total organic carbon and inorganic contaminants. The program's Sediment Grain Analyses data are available as part of the U.S. EPA NCA Coastal Bays Database[31].

As part of the Maryland Coastal Bays Sediment Mapping Project, the Maryland Geological Survey mapped the chemical and textural characteristics of shallow sediments in Maryland's coastal bays using core and surficial grab sample data from 1991 to 1997[32] (MGS 2012). A total of 346 sediment samples were extracted from 32 cores, with one sample falling within the ASIS boundary. Core samples were analyzed for water content, textural properties (percent gravel, sand, silt, and clay), chemical properties (total nitrogen, carbon, sulfur, and phosphorus), and concentrations of eight metals. A total of 988 surficial sediment samples were collected (one every 500 m) and analyzed for the same chemical and textural parameters as core samples, and additionally for reactive and organic carbon[44] (MGS 2012). Approximately 90 of the 988 surficial samples were collected within the ASIS boundary. Lastly, 411 surficial samples were collected to assess textural parameters via Rapid Sediment Analysis, with about 80 of these samples falling within the ASIS boundary. Results from these analyses were used to map the distribution of sediment type and chemical content. Separate year-end reports were developed for different portions of the bays. A final database[32] and a synthesis report[33] were submitted to the Coastal Zone Management Program of the Maryland Department of Natural Resources (Wells and Conkwright 1999). This synthesis report includes citations for surficial/shallow sediment studies in Assawoman and Isle of Wight Bays (Wells et al. 1994a, b); Newport and Sinepuxent Bays (Wells et al. 1996); and the Maryland portion of Chincoteague Bay (Wells et al. 1997, 1998).

In 2010, the ASIS Resource Management GIS Division produced and published surficial sediment maps of the Maryland/Virginia Coastal Bays including grain size and sediment contaminant data[248] (ASIS 2010b; see also *ASIS—Sediment contaminants*). Textural characteristics data include percent sand, clay, and silt. The textural analyses are based on sediment dry weight in grab samples collected in Maryland between 1991 and 1996 and in Virginia between 2006 and 2007 by the Maryland Geological Survey and the National Park Service. The Maryland sediment study was supported by MMS/AASG Continental Margins Program Contracts and NOAA awards. The Virginia study was supported by the National Park Service.

The USDA SSURGO Database contains soil maps for the counties that encompass ASIS (Accomack County, VA and Worcester County, MD; USDA NRCS 2004a, b). These maps include the bayside portions of ASIS[34]. This dataset is a digital soil survey prepared by digitizing maps or by revising digitized maps using remote sensing and other information. The maps depict types and distributions of soils at a spatial resolution of 1:15,840. The database also includes a field-verified inventory of soils and non-soil areas. The metadata for both counties describe the dataset as "the most detailed level of soil geographic data developed by the National Cooperative Soil Survey" (USDA NRCS 2004a, b).

The Offshore Sand Resources Study of the Maryland Coastal and Estuarine Geology Program occurred offshore of the ASIS seaside boundary, but maps the shoals outside the park that are assessed for dredging and beach nourishment resources (Conkwright 2011). Sediment samples were collected as part of an overall effort to develop a three-dimensional model of shoal bathymetry, topography, and stratigraphy, as well as sand volume and variability. Sediment samples were extracted from 56 cores and supplemented with more than 3,000 sediment samples from more than 200 archival cores collected by the U.S. Minerals and Mangement Service and the U.S. Army Corps of Engineers. The cores were analyzed for percent sand/gravel/mud, mean sand grain diameter and sorting (standard deviation), and vertical variations throughout the core sample. Sediment samples were correlated with seismic data to interpret shoal stratigraphy. A digitized map of sand study areas off the mid-Atlantic coast is available as a geodatabase file feature class produced by MMS (Johnson 1999).

Also as part of the Offshore Sand Resources Study, the Maryland Geological Survey conducted vibracoring in 1995 on a shoal field which extends from 6.4 km to 19.3 km offshore of Assateague Island (see also *ASIS—Hydrogeologic framework*). Forty-three 6-m vibracores were collected on five shoals within the shoalfield[48] (Conkwright and Williams 1996). Samples were classified for their sand resource potential based on grain size, sorting, and depth. Sand volume was calculated for each resource classification. A feature class map of estimated offshore shoal habitat was produced by the U.S. Fish and Wildlife Service in 2006 (Forsell 2006).

The Maryland Geological Survey examined textural data from 163 vibracores originally collected by the U.S. Army Corps of Engineers as part of the Ocean City Beach Replenishment Project[46] (Kerhin et al. 1999; see also *ASIS—Hydrogeologic framework*). The data extends from the Ocean City Inlet to the Maryland/Delaware line and from the shoreline to 5.6 km offshore. While most of the dataset lies north of ASIS, the park boundary extends about 250 m into the Ocean City Inlet.

During the summers of 1997-98, a consortium of federal and state environmental agencies conducted the Mid-Atlantic Integrated Assessment Estuaries program to characterize the environmental condition of the four major estuaries, including the Maryland-Virginia coastal bays (EPA 2002). The assessment included measurement of total organic carbon in the sediments.

Sediment samples were collected as part of the ASIS North End Restoration Project[10] (ASIS 2012; see also *ASIS—Bathymetry* and *Hydrogeologic framework*). In 2005, sediment samples were collected from constructed berm notches and analyzed for grain size (see Project Timeline; ASIS 2011a). Graphs of grain size distributions derived from these terrestrial samples are available from ASIS. Beginning in 2003, sediment samples were collected during project dredging and annually as part of the U.S. Army Corps of Engineers beach elevation profiles to document beach and dredge area sediment characteristics. The project's GIS datasets are listed and described in the North End Restoration Project Datasets and Contacts document (ASIS 2011b). Many of the datasets are available for download on the password protected National Park Service Natural Resources Data Store or by contacting ASIS.

The National Park Service held a Geologic Resource Evaluation scoping meeting for Assateague Island National Seashore in Berlin, Maryland on July 26 to 28, 2005[49] (Thornberry-Erlich 2005a). Participants at the meeting discussed the status of geologic mapping in the park. Participants identified a need for sediment type and distribution data, as well as other data types. The report identified several potential sources of this information including the Maryland Geological Survey Coastal Bays Sediment Mapping project; seismic and sidescan surveys conducted in ASIS nearshore environments since 2002; work by the Geologic Resource Division; and an unpublished geomorphic landform map for ASIS.

Sediment contaminants

Sediment contaminant data collected in the vicinity of ASIS are included in EPA's NCA and NARS (see National and Regional Datasets—Sediment contaminants), as well as the following localized data sets.

In 1993, surficial sediment contaminant data were collected in the bays bordering ASIS as part of a larger Coastal Bays Joint Assessment to assess the ecological condition of the Delaware and Maryland coastal bays[45] (Kutz 1999b). Sediment grab samples were taken at 68 stations within Assawoman and Chincoteague Bays bordering ASIS for analysis of organic and inorganic contaminants. Of these samples, only a random subset of 10 samples from the coastal bays was processed in the laboratory. The resulting Sediment Chemistry Analyte Concentration data set presents measured concentrations of a suite of analytes identified by the NOAA National Status and Trends suite of contaminants. The Sediment Analyte Concentration Data are available as part of the U.S. EPA NCA Database.

As part of the Maryland Coastal Bays Sediment Mapping Project, the Maryland Geological Survey mapped the chemical and textural characteristics of shallow sediments in Maryland's coastal bays using core and surficial grab sample data from 1991 to 1997[32] (MGS 2012). A total of 346 sediment samples were extracted from 32 cores, with one sample falling within the ASIS boundary. Core samples were analyzed for water content, textural properties, chemical properties (including total nitrogen, sulfur, and phosphorus and total, organic, and reactive carbon content), and concentrations of eight metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn). In addition, a total of 988 surficial sediment samples were collected (one every 500 m) and analyzed for the same chemical and textural parameters as core samples[44] (MGS 2012). Approximately 90 of the 988 surficial samples were collected within the ASIS boundary. Results from these analyses were used to map the distribution of sediment type and chemical content. Separate year-end reports were developed for different portions of the bays. A final database and synthesis report was submitted to the Coastal Zone Management Program of the Maryland Department of Natural Resources[32, 33] (Wells and Conkwright 1999).

In 2010, the ASIS Resource Management GIS Division produced and published surficial sediment maps of the Maryland/Virginia Coastal Bays including grain size and sediment contaminant data (see also *ASIS—Sediment grain size and organic content*). Sediment contaminants maps report on the distribution and levels of nitrogen, phosphorous, carbon, cadmium, sulfur, zinc, nickel, maganese, lead, iron, copper, and chromium. Chemical analyses are based on sediment dry weight in grab samples collected in Maryland between 1991 and 1996 as part of the Maryland Coastal Bays Sediment Mapping Project (see *records 32, 33, and 44*) and in Virginia between 2006 and 2007 by the Maryland Geological Survey and the National Park Service. The Maryland sediment study was supported by MMS/AASG Continental Margins Program Contracts and NOAA awards. The Virginia study was supported by the National Park Service.

Water chemistry and water quality

Water-chemistry and water-quality data for ASIS consist of national and regional datasets (see *National and regional Datasets*), as well as the following localized datasets.

A two-part report (Lea 2001; Lea and Wagner 2002) describes NPS monitoring program of estuarine water column parameters in the coastal bays abutting ASIS since 1987. Data summaries and reports on the ASIS water quality monitoring program are available in two documents (NPS WRD and ASIS 1991; Sturgis 2001). ASIS Resource Management staff also monitor ocean beaches for *Enterococcus* bacteria and fecal coliform bacteria from early May through mid September to meet EPA criteria for beach water quality[87].

Water quality studies that have occurred at ASIS are described and summarized in Orth et al (2006). This report states that water-quality surveys at ASIS commenced in the 1970s and assessed nutrients, turbidity, and phytoplankton within the coastal bays. Long-term monitoring began under the Maryland Department of Natural Resources in the 1990s (MD DNR 2004). An assessment of eutrophication trends is provided by Boynton et al. (1996). Many organizations participate in monitoring the water quality of the Maryland coastal bays through the Mayland Coastal Bays Program, including ASIS, MD DNR, and volunteers[85, 86]. Water-quality monitoring stations exist throughout Chincoteague Bay, including stations within the ASIS boundary (MD DNR 2012c). Wazniak et al. (2004) summarized Mayland Coastal Bays Program water-quality data from 2000-2003[84] (nutrient concentration, chlorophyll, DO, total suspended solids, and harmful algal bloom species). In the southern bays (Virginia), VIMS conducted water quality studies from 1997 to 1999 (Wesson et al. 2000) and the Virginia Coast Reserve Long-term Ecological Research Project has taken measurements from 1992 to the present.

Two hundred-fifty total sites were sampled divided between Assawoman and Chincoteague Bays in Maryland and Rehobeth and Indian River Bay in Delaware. GPS locations of the sampling stations are contained within a separate dataset (Kutz et al. 1999). The data were collected as part of the EPA EMAP-Estuaries Program, a program designed to assess the ecological condition of the bays in comparison with historical condition (Price et al. 1993).

During the summers of 1997 and 1998, a consortium of federal and state environmental agencies conducted the Mid-Atlantic Integrated Assessment Estuaries program to characterize the environmental condition of the four major estuaries, including the Maryland-Virginia coastal bays (EPA 2002). Measured water-quality indicators included total nitrogen and phosphorus, chlorophyll a, water clarity, and dissolved oxygen.

Submerged habitats and biological communities

Seagrass distribution

The Virginia Institute of Marine Science (VIMS) has produced periodic maps of submerged aquatic vegetation (SAV) in Chesapeake Bay and the Maryland coastal bays since 1986. Mapping data are compiled in reports representing one year of coverage. Annual coverages and reports have been produced since 1997, and individual coverages exist also for 1986, 1989, 1991, 1992, 1994, and 1995[118]. The reports (e.g., Orth et al. 1987, 1998) describe the boundaries and density classes of mapped SAV each year. Data from 1974 to 1990 are compiled into a single coverage (however coverages earlier than 1986 include SAV in Chesapeake Bay only, not Chincoteague Bay). SAV was mapped through interpretation of 1:24,000 scale aerial photographs.

A two-part report provides information on SAV monitoring by ASIS from 1998 to 2000 within the coastal bays associated with ASIS[119] (Lea 2001; Lea and Wagner 2002). Part I of the report describes a study of SAV water quality habitat requirements. Part II assesses the efficacy of SAV epiphytes as an indicator of SAV condition in an attempt to establish a tool for assessing stress and decline earlier than may be possible through mapping via remote sensing techniques. No GIS data are associated with these reports.

Orth et al. (2006) describes natural recovery of eelgrass (*Zostera marina*) in the northern coastal bays of the Delmarva Peninsula, including Chincoteague Bay, since catastrophic declines during the 1930s[120]. In the southern coastal bays (south of ASIS), recoveries are described resulting from seed dispersal experimentation and restoration efforts in 1997 to 2000 and 2001 to 2004. Changes in seagrass coverage were assessed by comparing 2004 aerial photographs with aerial photographs collected in the coastal bays beginning in 1986 and continuing annually through 2003, except for 1988.

Biological communities and species inventories

The U.S. Fish Wildlife Service inventoried wetlands of Worcester County, Maryland (encompassing the Maryland portion of ASIS) in 1981 as part of the National Wetlands Inventory (NWI)[132] (USFWS 1981; see also *Regional and National Datasets*). This data set includes and classifies all freshwater, estuarine, and marine wetlands located in Worcester County, Maryland. The original NWI data were merged into a single dataset and cut to include only the area within Worcester County and the Maryland Coastal Bays watershed. Digital and hardcopy maps are based on interpretations from 1992 aerial photography (1:20,000 to 1:132,000 scale) and have a 0.4- to 1.2-ha minimum mapping unit depending on wetland type and scale of source aerial photography. Maps and digital data files contain information about wetland locations, types, and attributes.

In 1993, taxa, infaunal, and epifaunal counts; abundance and biomass data; and benthic diversity indices data were collected in the bays bordering ASIS (Chaillou et al. 1996). This data collection was part of a larger Coastal Bays Joint Assessment of the ecological condition of the Delaware and Maryland coastal bays. Sixty-eight sampling stations were established in Assawoman and Chincoteague Bays bordering ASIS, with approximately six of these falling within or overlapping with the ASIS boundary. Benthic abundance was counted by taxon in each grab sample representing sediment depths up to 10 cm. The Benthic Abundance and Grab Information Data Sets[31] present information on the benthic macroinvertebrate populations at each station. The data are available as part of the U.S. EPA NCA Coastal Bays Database.

Juvenile fish abundance, composition, and length data were collected from July to August 1993 in the Maryland (and Delaware) Coastal Bays as part of the EPA Coastal Bays Joint Assessment[121] (Kutz et al. 1996). The Fish Community Trends dataset is a Microsoft Excel® spreadsheet containing fish data collected from beach seining out to 46 m from shore at historical survey sites in Maryland coastal bays. Seining took place at 109 sites within Assawoman and Chincoteague Bays in Maryland and at additional sites in Delaware. Six of the sampling stations abut or fall within ASIS boundaries. The data were compared to historical information to assess if population changes could be related to water quality trends in these bays. This dataset was collected as part of the EPA EMAP-Estuaries Program, a program of the EPA designed to assess the ecological condition of the bays in comparison with historical condition (Price et al. 1993). Project metadata are not FDGC compliant.

An Environmental Sensitivity Index atlas has been developed for Virginia by NOAA NOS and the NOAA Chesapeake Bay Office[140] (NOAA 2012). The atlas was developed following the structure and format of ESI's developed for U.S. shorelines (see *National and Regional Datasets*). The ESI atlas for Virginia includes digital data in the form of a geodatabase and individual shapefiles, a report, and PDF maps that characterize marine and estuarine environments and wildlife according to their sensitivity to oil spills. Digital data files relevant to ASIS (and COLO) include shoreline habitat mapping and shoreline classifications; sensitive biological resources; and human resource information. The summary document describes the methods and data sources used to collect comprehensive data on Virginia shoreline habitats and sensitive resources.

ASIS conducted a two-year assessment of Assateague salt marshes from 1992 to 1993 through line site surveys along the length of the Maryland portion of ASIS[122] (Furbish et al. 1994). Data on the distribution and abundance of small mammals, arthropods, snails, fiddler crabs, flora, and muck depth were collected and combined with similar information collected in along mainland areas of Maryland coastal bays by the Maryland Department of Natural Resources. The combined data set was analyzed to test for differences between ASIS salt marshes and those in surrounding areas. The objectives of the assessment were to compare salt marsh areas with natural versus altered geomorphological processes and with differing grazing pressures. Salt marsh flora and fauna data were collected using taxon-specific methods along line transects. A total of four pairs of grazing exclosure and control plots were monitored.

The Maryland Department of Natural Resources (MD DNR) maintains a set of digital data files containing records of wetlands locations and classifications within Maryland as defined by the U.S. Fish and Wildlife Service[124] (MD DNR 1989). The dataset is based on aerial photo interpretation and provides wetland coordinate and attribute information for a 3.75-minute^2 block area in Worcester County, Maryland. The dataset is part of a series developed in Maryland to assist regulatory wetland management programs and resource management programs in the state. All photo-interpretable wetlands in the area were mapped, which in general equated to a 0.2-ha minimum mapping unit depending on wetland type and the scale of source photography. Sources included 1:40,000 scale USGS/MD DNR aerial photographs and 1:12,000 scale MD DNR digital orthophoto maps. The wetland maps were compiled through manual photo interpretation, field checking of wetland photo signatures, and supplementation with soil survey data.

Associated with the North End Restoration Project, vegetation monitoring on ASIS was conducted from 1996 to 2003[126] (Lea 1998a, b; Lea 2000). Vegetation community type was identified at 381 to 412 randomly selected points on the North End following classification derived from The Nature Conservancy. The project was designed to detect changes in vascular plant community composition potentially resulting from the 2001 restoration and stabilization at the North End. The study monitored vegetation association frequency before and after berm construction. The 1996 to 2003 dataset contains species, vegetation community types, locations, and abundance at sampled sites (Sturm 2003).

Species- and taxa-specific data for ASIS include:

1. A final report, yearly reports, and three shapefiles representing locations of Sea Beach Amaranth monitored from 2000 to 2005[117] (Lea et al. 2002).
2. Recorded locations for three exotic plant species that are managed by the NPS Resource Management Division. In 1999 to 2001, GPS units were used to mark the locations of these exotic species. A shapefile of the recorded locations accompanies an unpublished report on three years of management of these exotic species in the park (McIntyre et al. 2001).
3. Five shapefiles that mark the locations of nest sites, attempted nest sites, and crawl paths for loggerhead turtles sited on ASIS from 1998 to 1999[111] (Rodriguez 1999).
4. A database and reports spanning 1993 to 2006 on Piping Plover monitoring and management, population, habitat, nesting areas, and brood estimates[114] (Bottita et al. 1993-2006; Rodriguez 2006d[112], 2006e[113]).
5. Stranding data for marine mammals and turtles in the form of Microsoft Word® documents, PDFs, Access® databases, and Excel® spreadsheets. In some cases, UTM coordinates were recorded to document stranding locations. Stranding reports are available from 1994 to 2003[115] (ASIS 1994 to 2003[)].
6. A report (ASIS 2003) and GPS locations of plants that are designated as rare to the state of Maryland found on ASIS from 1998 to 2003[116].
7. A final report (Knisley et al. 2002) and annual reports from 2001 to 2005 on surveys for two rare species of tiger beetles, which occur only on ASIS[125].
8. Mosquito monitoring data and reports for surveys from 2000 to 2002[127].

Fire Island National Seashore (FIIS)

<u>Bathymetry</u>

Bathymetry datasets of varying resolutions exist for bayside and oceanside areas of FIIS. Modern high-resolution surveys have been conducted within sub-tidal areas of FIIS, yet, at the time of this publication, additional surveys were required to achieve full high-resolution coverage of submerged areas within the park. The following data descriptions represent the existing local and park-specific datasets available for FIIS at the time of the inventory's completion, as well as a number of additional bathymetry datasets acquired post-inventory. National and regional bathymetry relevant to FIIS are described in the *National and Regional Datasets—Bathymetry* section.

The NOAA Estuarine Bathymetry Project[234] (NOAA 2007) includes 1-arc-second (about 30-m) resolution bathymetric digital elevation models (DEMs) that encompass the Great South Bay section of FIIS [4] (NOAA NOS 1998a). The Great South Bay bathymetric models are based on 124,314 soundings (averaging 53 m apart) derived from NOAA NOS hydrographic surveys conducted from 1933 to 1951 (NOAA NOS 2011). Sixteen 7.5-minute DEMs and two one-degree DEMs are available for Great South Bay.

The School of Marine and Atmospheric Sciences at The State University of New York (SUNY) at Stony Brook developed multibeam bathymetry data for bayside areas of FIIS through a "model domain and gridding" effort as part of the Great South Bay Project[235] (Flagg et al. 2011; see also *FIIS—Hydrography*). Although multibeam mapping was restricted to FIIS bay-side areas, the project's bathymetry grid covers Great South and Moriches Bays and extends to the ocean side of FIIS, offshore to the edge of the continental shelf, and east and west from Sandy

Hook almost to Montauk Point. This map was created by interpolating existing bathymetry data from NOS hydrographic surveys, and SUNY Stony Brook multibeam surveys conducted since 2001, onto an area grid. Incorporated within the bathymetry dataset are sidescan data collected in 2002 to assess sub-tidal oyster reefs (Clapp and Flood 2004), as well as bottom topography data for the Fire Island Inlet and Great South Bay (Flood 2010). The Great South Bay Project created a final model bathymetry map specific to Great South and Moriches Bays, along with thumbnail bathymetry maps for areas such as the Fire Island Inlet, Old Inlet Breach, and Jones Inlet (Flagg and Wilson 2012).

In 2006, bathymetry mapping was conducted within a portion of Great South Bay as part of a pilot study conducted by the University of Rhode Island, Washington College, and NPS to develop a protocol for habitat mapping in very shallow water (less than 5 m)[237] (Shumchenia and King 2010). The study covered two small areas (1 km by 0.73 km and 0.95 km by 0.3 km) near Watch Hill and Long Cove in Great South Bay with depths ranging from 0.8 m to 3 m[210] (Hiller 2006). The study concluded that interferometric sonar systems are effective and efficient instruments for rapidly attaining both sidescan sonar and bathymetry data in very shallow water, with a much greater footprint than single-beam sonar and a greater swath width than multibeam systems (swath widths of 8 times water depth vs. 4 times for multibeam). Interferometric bathymetry data accuracies for this study were less than 5 cm (Hiller 2006). Swath widths of 10 m were achieved even in the shallowest areas and 40-m swaths were possible in areas with depths 2 m or greater. The instrument achieved 25% bathymetric coverage in water depths less than 1 m and 100% coverage in depths greater than 2 m. Products included 20-cm bathymetry grids for the two survey areas.

From 2007 to 2010, Burroughs and Chapin Center for Marine and Wetland Studies at Coastal Carolina University conducted high-resolution mapping of nearshore bathymetry along the coast of FIIS[238] (Gayes et al. 2010). The study was designed to provide “first-of-its kind” nearshore bathymetry data and facilitate assessment of beach erosion causes (Gayes et al. 2009; see also *FIIS—Hydrogeologic framework*). The surveys collected detailed bathymetry at two sites (Lighthouse and Watch Hill) along the FIIS shoreface, each measuring approximately 4.5 km and extending from 0 km to 4 km offshore. Single-beam mapping was conducted at the Watch Hill site in 2007. In 2009, single-beam and multibeam mapping was conducted in an area of the FIIS Lighthouse Site measuring 15.1 km^2. Survey depths ranged from 0 to 10 m. In shallow waters from 0 km to 1 km offshore, data were collected using a shallow-water single-beam system. In deeper waters from 1 km to 4 km offshore bathymetry was mapped with a shallow-water multibeam sonar system. Only the single-beam survey data collected from 0 km to 1 km offshore overlap partially with the park boundary, which extends out about 0.3 km seaward from the shoreline. Products include single-beam grids (Hapke et al. 2010.), a multibeam grid from the 2009 Lighthouse survey, 1-m bathymetric DEMs that integrate the single beam and multibeam data into continuous imagery, 1-m depth contours, and maps of single-beam and multibeam survey footprints for both sites.

USGS collected fathometry bathymetry data in 1996 to 1997, and multibeam bathymetric data in select areas in 1998, as part of a surficial and subsurface geophysical survey of the seafloor offshore of southern Long Island. The study area extended from the 8-m isobath to about 10 km offshore along the entire oceanside length of FIIS (from west of the Fire Island Inlet to east of the Shinnecock Inlet; Schwab et al. 2000b, c). Bathymetric data were collected digitally with a

200 kHz fathometer. Fathometer data were processed to remove water-depth variations due to vessel heave, transducer draft, and tidal fluctuations. Resulting bathymetric data, with a vertical resolution of about 1 m, were gridded and contoured onto a 300-m grid. In 1998, Simrad EM 1000 Multibeam Echosounder surveys were conducted to acquire high-resolution bathymetric data coincident with sidescan-sonar backscatter data (see also *FIIS—Acoustic seabed characterization*). This multibeam system ensonified a swath of seafloor up to 7.5 times the water depth. Horizontal resolution was 1.3 m to 5.0 m and the vertical resolution was 0.2 m to 0.5 m. Digital multibeam data were processed using software developed by the Ocean Mapping Group at the University of New Brunswick. Products include 2-m bathymetric contours overlain on a sidescan sonar mosaic (see also *FIIS—Hydrogeologic framework and Acoustic seabed characterization*).

The NOAA Coastal Services Center published coastal topographic and bathymetric lidar survey data collected along the New York, New Jersey, Maryland, and Virginia coastline as part of the National Coastal Mapping Program (NOAA CSC 2006; see also *National and Regional Datasets—Bathymetry*). The survey footprint and metadata can be viewed on the NOAA CSC Digital Coast Data Access Viewer (NOAA CSC 2012).

Valentine (2011) reports that USGS and Coastal Carolina University conducted mapping of the Fire Island seashore in 2011, which will provide high-resolution bathymetry from wave breaking depths to about 10 km offshore. EAARL lidar will also be flown to collect seamless terrestrial and benthic topography and shallow water bathymetry data. These data were not available at the time of this publication.

<u>Hydrography</u>

Wave height, direction, and periodicity

Real-time wave data in the vicinity of FIIS are collected by three buoys owned and maintained by NOAA National Data Buoy Center: moored buoys 44065, 44025, and 44017 (Figure 23, Table 9; NOAA NWS 2012b). All three buoys are located a fair distance from the park. Buoy 44065 (LLNR 725) is at the entrance to NY Harbor, about 45 km southwest of the park; station 44025 (LLNR 830) is located about 61 km south of Islip, NY and 43 km south of the Fire Island light house; and station 44017 (LLNR 665) is about 36 km southwest of Montauk Point, NY and 57 km east of West Hampton Beach, NY.

Tide range, phase, and currents

Data relevant to tide range, phase, and current at FIIS are collected at four locations (Figure 23, Table 9). Three stations are owned and maintained by the USGS (01310521, 01309225, 01310740, USGS 2012b), and Station L3B (formerly P7) is maintained by LIShore Program (LIShore 2012). Station L3B is within the park boundaries and provides the most relevant data to the park. The three USGS stations are all west of the park boundaries. In order of proximity to FIIS, Station 01309225 is located at Veactian Shores Park within Great South Bay at Lindenhurst, NY; Station 01310521 is at Hudson Bay at Freeport, NY; and Station 01310740 is located at Reynolds Channel Point Lookout, NY.

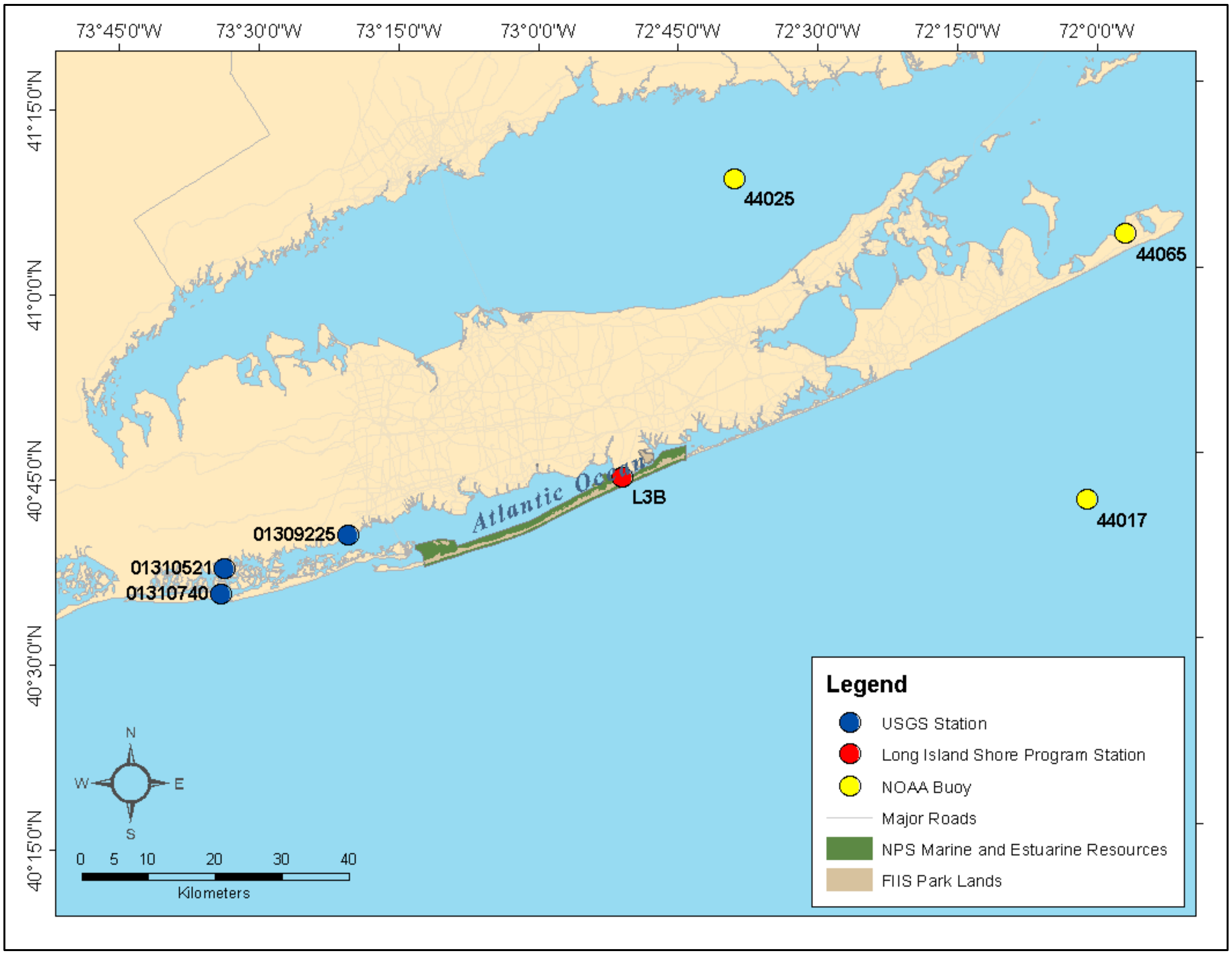

Figure 23. Hydrographic data collection stations in the vicinity of Fire Island National Seashore (LIShore 2012, NOAA NWS 2012b, USGS 2012b).

In addition to hydrographic data collection stations, there are several additional hydrographic data sources relevant to FIIS. A book about Great South Bay contains detailed information about tidal currents, circulation, and exchange in the bayside portions of FIIS (Schubel et al. 1991). Similarly, in 2000, the Marine Sciences Research Center from SUNY at Stony Brook published the results of numerical hydrodynamic modeling in Great South Bay (Conley 2000). The report assesses the potential impacts of barrier island breaches on the circulation and water quality of Great South Bay (see also *FIIS—Water Quality*). An early focus of the Great South Bay Project (Flagg et al. 2011; Flagg and Wilson 2012) was the impact of storm breaches on the ecology of the region as a result of changes in circulation, salinity, temperature, stratification, nutrient supply, productivity, bedform and SAV. Two potential breach locations, Old Inlet and Atlantique, have been examined by artificial breaching at Fire Island.

Table 9. Hydrographic monitoring stations in the vicinity of Fire Island National Seashore (LIShore 2012, NOAA NWS 2012b, USGS 2012b)

FIIS	NOAA NDBC Moored Buoy			LI Shore Program	USGS Stations		
Station Codes	**LLNR 725 44065**	**LLNR 665 44017**	**LLNR 830 44025**	**Smith Point L3B**	**01310521**	**01309225**	**01310740**
Wind Direction	+	-	+	-	-	-	+
Wind Speed	+	+	+	-	-	-	+
Wind Gust	+	+	+	-	-	-	+
Wave Height	+	+	+	-	-	-	-
Dominant Wave Period	+	+	+	-	-	-	-
Average Period	+	+	+	-	-	-	-
Mean Wave Direction	+	+	+	-	-	-	-
Atmospheric Pressure	+	-	+	-	-	-	+
Pressure Tendency	+	-	+	-	-	-	-
Air Temperature	+	-	+	-	-	-	+
Water Temperature	+	-	+	+	-	-	+
Dew Point / Relative Humidity	+	-	+	-	-	-	+
Water Level	-	-	-	+	+	+	+
Conductivity/Salinity	-	-	-	-	-	-	+

Hydrogeologic framework

Hydrogeologic framework maps and data relevant to FIIS are available through the New York State (NYS) GIS Clearinghouse (NYS 2012b). The website provides access to marine and terrestrial geologic maps; digitized soil maps from the USDA Natural Resources Conservation Service's (NRCS) Soil Survey Geographic Database (SSURGO; USDA NRCS 2001a); hazardous waste remediation sites tracked by the NYS Department of Environmental Conservation (DEC); a map of unconsolidated aquifers in New York State; aquifer maps at a 1:24,000 scale produced since the 1980s by USGS; and county-level bedrock geology, hydrologic framework, soils, erosion, estuary, and surficial geology maps.

From 2008 to 2010, high-resolution nearshore mapping along the coast of FIIS was conducted by the Burroughs and Chapin Center for Marine and Wetland Studies, Coastal Carolina University[238] (Gayes et. al 2010). In addition to seafloor morphology (see FIIS *Seabed Characterization*), the study examined nearshore sediment dynamics, suitable borrow sites for nourishment projects, and the stability of nearshore ridges at or near two FIIS sites (Lighthouse and Watch Hill). A poster by Miller et al. (2009) discusses the impacts of the area's hydrogeologic framework on sediment transport and beach erosion. Hapke et al. (2010) examine how nearshore geologic framework and shoreline changes may influence sediment budgets along Fire Island.

A book on barrier breaches in Great South Bay (Tanski et al. 2001) provides a detailed overview and history of studies related to inlet formation and island breaching on FIIS. The book discusses studies initiated by NPS and conducted by the U.S. Army Corps of Engineers (1996) and USGS (Allen et al. 2002) to assess the vulnerability of FIIS to storm breaches and potential changes to bayside areas of FIIS.

Surface and groundwater pathways

In addition to localized sources below, data on surface-water level, stream flow, and groundwater level are provided by the USGS National Water Information System (USGS 2012b, see *National and Regional Datasets—Hydrogeologic framework*).

Schubert (2010) describes the shallow groundwater flow system at FIIS. This information was produced through a cooperative study between USGS and FIIS to collect groundwater levels and water-quality (nutrient) samples, develop a three-dimensional model of the shallow (water-table) aquifer system and adjacent marine surface waters, and calculate nitrogen loads in simulated groundwater discharges from the aquifer to back-barrier estuaries and the ocean.

An earlier work by Schubert et al. (1997) consists of a four-page fact sheet, which evaluates ground-water resources in Long Island and describes techniques for simulating ground-water flow[205]. Relevant to FIIS (as well as GATE and SAHI), the fact sheet provides a description of Long Island's aquifers, stresses on the area's ground-water flow system, and patterns and rates of groundwater movements. In addition, the document presents information on Long Island's hydrogeologic framework, hydrologic boundaries, and hydraulic stresses, including the results of a particle tracking procedure used to define flow paths and delineate recharge areas. A GIS database was developed to incorporate model input, output, and particle tracking data.

Monti and Scorca (2003) present the results of a USGS Water Resources Investigation of total annual nitrogen discharge loads to the South Shore Estuary Reserve from surface and groundwater pathways in Nassau and Suffolk Counties, Long Island, New York[208]. The Reserve encompasses FIIS, extending from mean high water on the ocean side of the barrier island and inland to the limits of Long Island's bayside watersheds. Descriptions of Long Island hydrogeologic units, as well as tables and graphs of nitrogen load distributions are provided in the report. No GIS data layers are presented. Discharges from shallow and deep ground water were simulated from a ground-water-flow model calibrated to steady-state (1968-83) conditions. Geographic, seasonal, and long-term nitrogen concentration trends were analyzed using 1971 to 1997 water-quality data from 13 major south-shore streams and 192 south-shore wells. Annual total nitrogen loads from 11 of the streams were calculated using long-term discharge records.

Buxton and Smolensky (1999) simulated the effects of development on groundwater flow in Long Island providing surface and groundwater predictions applicable to FIIS, as well as GATE and SAHI (see *National and Regional Datasets—Surface and groundwater pathways*).

An earlier three-page hydrologic investigations atlas (Smolensky et al. 1990) presents seven maps and vertical sections showing the hydrogeologic framework of deposits that form Long Island's ground-water system[204]. These include 1:250,000 scale maps showing the configuration of the bedrock surface, the altitude of Cretaceous deposits and bedrock beneath the upper glacial aquifer, and the altitude of the upper surface of the Raritan Confining Unit, Gardiner's clay, and the Lloyd, Monmouth, Jameco, and Magothy Aquifers. Hydrogeologic data from more than 3,100 wells were used to interpret the altitude of the upper surface of each hydrogeologic unit. Seismic survey data from previous studies were used to correlate onshore and offshore data and to project the extent of hydrogeologic units offshore. The atlas provides a description of the erosional and depositional history in Long Island derived from a theoretical sedimentation model and consequent interpretations of the type, location, and thickness of sediments.

Bedrock geology and shallow stratigraphy

The NPS Geologic Resources Inventory (GRI) Scoping Report for FIIS identifies sources of relevant geologic mapping data (Thornberry-Ehrlich 2011b; see *National and regional Datasets—Hydrogeologic framework*).

USGS conducted high-resolution seismic reflection profiling surveys from 1996 to 1997 along the entire oceanside length of FIIS (from west of the Fire Island Inlet to east of the Shinnecock Inlet), from the 8 m isobath to about 10 km offshore (Schwab et al. 2000b, c). This subsurface survey was conducted to study the influence of the underlying geologic framework on the barrier-island system and its sand resources. Sub-bottom profile surveys were conducted using 2-7 Hz swept FM (chirp) and 300-3000 Hz Geopulse boomer sub-bottom profilers, a 100-3000 Hz sparker system, and related positioning and depth instrumentation. The profiling data were interpreted and mapped using Seisworks software. Profile images, sand thickness maps, and paleochannel thickness maps were developed from the seismic data. Horizontal positional accuracy is estimated at +/- 5 m. Sidescan sonar surveys, ground-truth sampling, and bathymetric measurements were also part of the intergrated mapping (see *FIIS—Bathymetry* and *Acoustic seabed characterization*).

Surficial geology

Acoustic seabed characterization

From 2008 to 2010, high-resolution nearshore mapping along the coast of FIIS was conducted by the Burroughs and Chapin Center for Marine and Wetland Studies at Coastal Carolina University[238] (Gayes et al. 2010). The study examined seafloor morphology, nearshore sediment dynamics, suitable borrow sites for nourishment projects, and the stability of nearshore ridges (see also FIIS *Hydrogeologic framework* and *Bathymetry*). While the focus of the study was on acquisition of nearshore bathymetry at two sites (Lighthouse and Watch Hill), backscatter intensity images were acquired along two 4.5-km oceanside stretches extending from 1 km to 4 km offshore using a bow-mounted Kongsberg EM3002d dual-head, shallow water multibeam bathymetry system. Data products include 1-m backscatter intensity imagery for both sites. While single-beam bathymetry data collected in association with this project overlapped with park boundaries, multibeam bathymetry and backscatter data fall outside of the park boundary, which extends only about 300 m seaward from the shoreline.

In 1996, the U.S. Geological Survey, in cooperation with the U.S. Army Corps of Engineers, began a program to produce geologic maps of the sea floor along the south shore of Long Island to investigate regional-scale sand-resource availability and the role of inner-shelf morphology and geologic framework in this coastal region. As part of this program, USGS conducted high-resolution sidescan sonar, seismic reflection profiling, multibeam sonar, and sediment sampling surveys along the entire oceanside length of FIIS in 1996 to 1997, from the 8-m isobath out to about 10 km offshore (Schwab et al. 2000b, c; see also *FIIS—Hydrogeologic framework* and *Bathymetry)*.

Side-scan surveys were conducted using a 100 to 105 kHz swept-frequency unit. Ship track lines were selected to provide continuous sidescan-sonar coverage of the seafloor, resulting in an average line spacing of 300 m. The sidescan-sonar data were logged digitally at a sample rate yielding a 0.18-m pixel resolution in the across-track direction and approximately 0.14-m pixel resolution in the along-track direction. The data were processed and mosaicked to produce a geographically correct, 4-m/pixel resolution sidescan mosaic. Surficial sediment samples were collected with a Van Veen grab and analyzed for grain size to ground-truth the sidescan sonar data. Multibeam backscatter (as well as bathymetric) data were collected with a Simrad EM1000 at selected sites in 1998. Horizontal positional accuracy of the surveys is estimated to be +/- 5 m. A full description of data acquisition and processing routines is presented in Foster et al. (1999). Regional interpretation of the mapping products are reported in Schwab et al. (1999, 2000b). Products related to acoustic seabed characterization include sidescan backscatter intensity imagery (Figure 24); a sidescan sonar mosaic and a second mosaic overlain with 2-m bathymetric contours; sediment textural data from grab samples; multibeam backscatter, shaded relief, and pseudo-color backscatter imagery of sand waves and shoreface-attached sand ridges; and an interpretive geologic map of surficial sediments off of the southern Long Island coast. The study provides comprehensive information about surficial sediment distribution and geomorphology in the vicinity of FIIS.

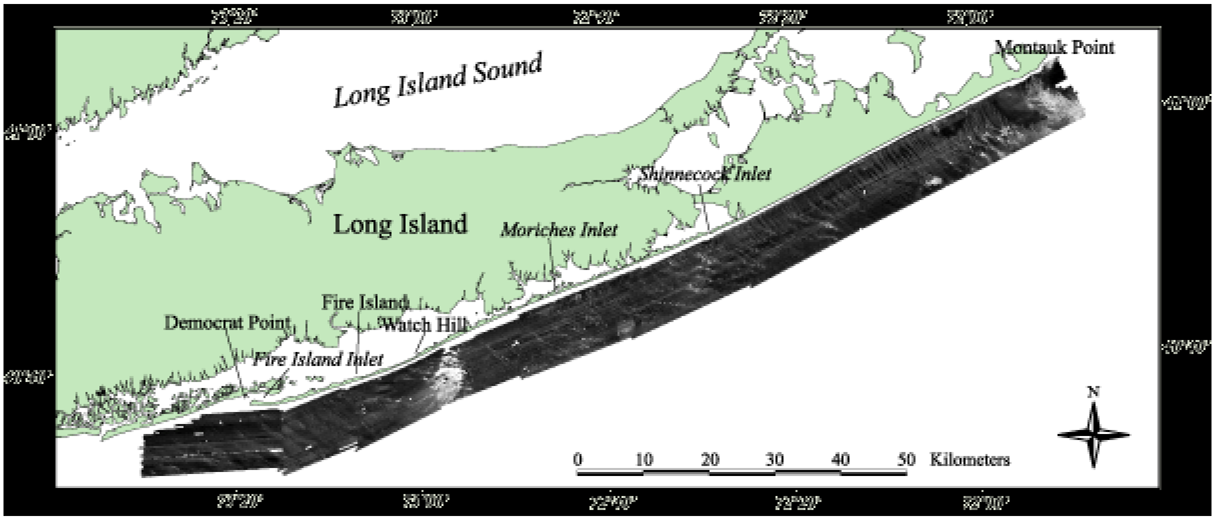

Figure 24. Sidescan backscatter intensity image extending along the FIIS shoreface from the 8 m isobath out to ~10 km offshore. Image from Schwab et al. (2000c).

In 2002, geophysical surveys using side-scan sonar and multibeam sonar were conducted in Great South Bay by SUNY at Stony Brook in order to identify and evaluate the morphology of sub-tidal relict oyster reefs. Backscatter intensity data were utilized to identify and describe previously undiscovered relict reefs. A project abstract is available online (Clapp and Flood 2004; see also *FIIS—Submerged habitats and biological communities*).

A team of scientists from URI, Washington College, and NPS conducted a pilot study in 2006 within a portion of Great South Bay to develop a protocol for shallow water habitat mapping[237] (Schumchenia and King 2010). The study compared the performance of sidescan sonar and interferometric sonar in producing bathymetry and backscatter intensity data simultaneously in very shallow waters (0 m - 5 m). The pilot study also compared these techniques with single beam sonar and tested approaches to ground-truthing. Dual simultaneous 100- and 400-kHz full spectrum sidescan surveys achieved approximately 100% coverage of bathymetry and backscatter intensity data. A 0.3-m pixel size mosaic was created with the full coverage sidescan survey data. Surveys using a QTC VIEW V single beam system were conducted along the same tracklines and achieved about 10% to 20% acoustic backscatter coverage. GeoSwath interferometric sonar system surveys re-traced some of the sidescan sonar transects and enabled expansion into shallower waters. Interferometric surveys were conducted in two areas—one measuring 1 km by 730 m and including mostly waters 2 m to 3 m deep; the second measuring 950 m by 300 m at a consistent depth of 0.85 m. In the first area, interferometric sonar achieved 100% bathymetric and sidescan coverage, via 21 track lines spaced 40 m apart. In the second shallower area, this instrument achieved 25% bathymetry coverage and 90% sidescan coverage via 8 lines spaced 50 m apart and one cross line survey. Surveying achieved sub-centimetric resolution of seabed features. The data were analyzed to determine the number and characteristics of unique acoustic classes. Fifteen ground-truth sample stations were chosen based on changes in backscatter intensity on the sidescan mosaic. Grab samples, sediment profile imagery, and underwater video collected at these stations aided interpretation of the acoustic data and the identification of benthic habitat. (Schumchenia and King 2010; see also *FIIS—Submerged habitats and biological communities*).

Sediment grain size and organic content
Sediment grain size and organic content data for FIIS consists of regional datasets such as EPA's NCA and NARS, CONMAP, usSEABED, the USGS Marine Aggregate Resources Project, and the East Coast Sediment Texture Database (see *National and regional Datasets—Sediment grain size and organic content*), as well as the following localized datasets.

The USGS Marine Aggregate Resources Project contains a GIS compilation of surficial sediment data for the New York-New Jersey region (Williams et al. 2006; see also *National and regional Datasets—Sediment grain size and organic content*). The compilation is based on data contained within USGS data series 118 (Reid et al. 2005). This dataset was geographically clipped from the usSEABED database to include only samples within the New York-New Jersey region. Examples of metrics contained within this parsed dataset include seafloor roughness, porosity, organic content, shear strength, color, grain size classification, and depth. Sampling points are contained within oceanside and bayside areas of FIIS (and GATE).

Related to this effort, USGS conducted a regional assessment of marine aggregates for the New York Bight region using digital geologic maps developed for the region from usSEABED data (Williams et al. 2003). The New York Bight region was selected for the development of gridded or point maps of seafloor sedimentary character due its dense high quality data coverage (Figure 25).

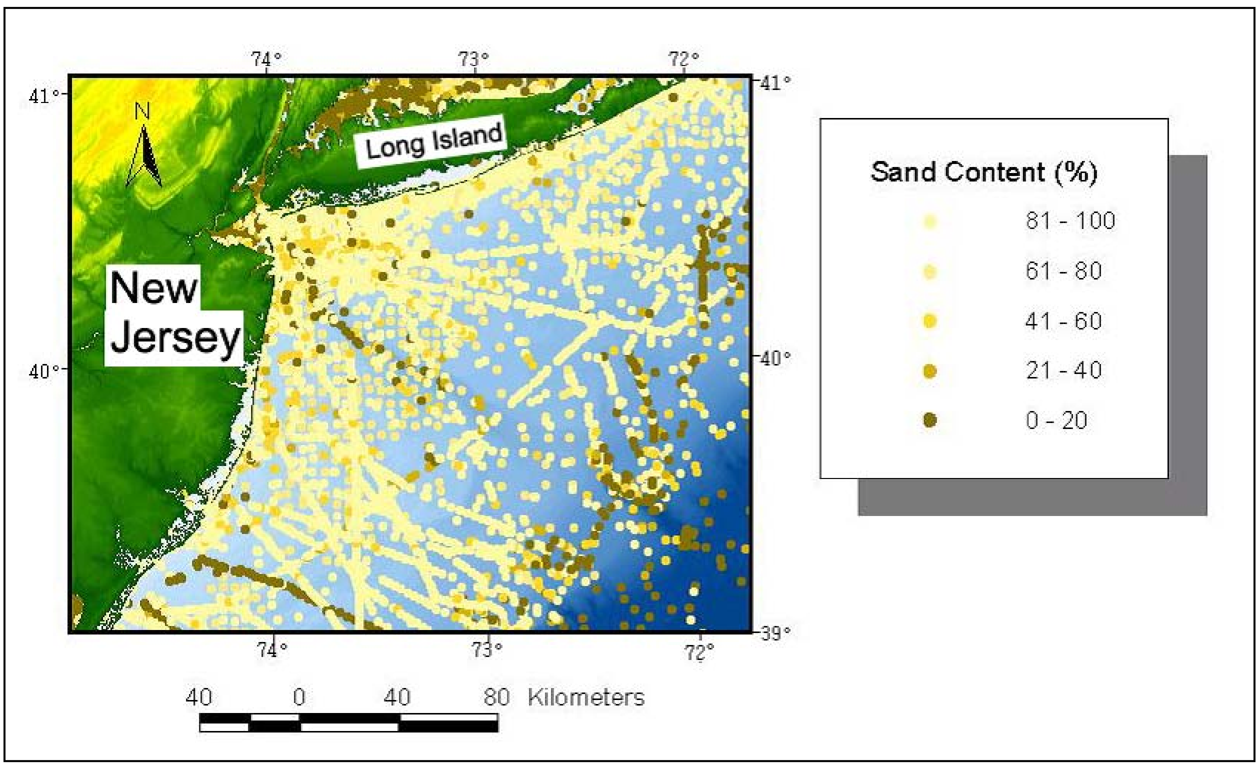

Figure 25. Map of the New York Bight continental margin showing sand distribution based on samples in usSEABED. Image from Williams et al. (2003).

A digital version of textural descriptions published by Jones and Schubel (1980) provides maps of surficial sediment textures and organic content in Great South Bay, as well as eelgrass distribution (see *FIIS—Seagrass distribution*). The data layer is published for inclusion in the usSEABED data collection. The data, including percent mass of sediment types and organic content, are summarized in tabular form and on a series of maps.

The dataset Shelf Sediments off Long Island Sound contains data from several surficial sediment grain size sampling stations in the vicinity of FIIS's seaside boundary (McKinney and Friedman 1970).

Schumchenia and King (2010) collected grab samples within Great South Bay for grain size analysis of surficial and subsurface sediments (see *FIIS—Acoustic seabed characterization*).

Sediment contaminants

Sediment contaminant data collected in the vicinity of FIIS are included in EPA's NCA and NARS (see National and Regional Datasets—Sediment contaminants), as well as the following localized data sets.

Hinga (2005) provides a brief synthesis of sediment contaminants within Great South Bay, including measurements in 1990 from an EPA Environmental Monitoring and Assessment Program (EMAP) station (Station VA-023), located about 500 m off the mouth of the Swan River in northeast Great South Bay[225].

The EPA STOrage and RETrieval (STORET) database contains regional contaminant data pertinent to Long Island and FIIS (EPA 2012b). The STORET data management system is a EPA national database containing raw biological, chemical, and physical data on surface and ground water. Two datasets include sediment contaminant data for Long Island collected by the State of New York and NPS from four NY counties (Kings, Queens, Nassau, and Suffolk) and Monmouth County, NJ (see also *FIIS—Water chemistry and water quality*). One dataset includes sampling data dating from 1965 to 1989 containing approximately 55 points within or abutting the FIIS boundary[197] (EPA 2006). The second dataset covers sampling conducted from 1990 to 2005 and includes nine sampling points within or abutting the FIIS boundary[197] (EPA 2006). These regional data were downloaded from the EPA STORET database, converted to GIS, and organized in a geodatabase with associated metadata. The data resolution is fine enough for specific park use. Contaminant data include iron, zinc, chromium, cadmium, copper, arsenic, heptachlor epoxide, DDE, DDT, PCB, BHC, dieldrin, endrin, hydrocarbons, aldrin, methoxychlor, lead, and chlordane.

Water chemistry and water quality

Water-chemistry and water-quality data for FIIS consist of national/regional datasets (see *National and regional Datasets—Water chemistry and water quality*), as well as the following localized datasets.

A book about Great South Bay contains water quality information pertaining to the bayside portions of FIIS (Schubel et al. 1991).

Hinga (2005) compiles water quality studies for Great South Bay, focusing particularly on water quality characteristics within FIIS boundaries. The report provides a synthesis of information on aqueous bacterial and chemical contaminants, eutrophication (nutrient levels and dissolved organic content), salinity distribution, water residence time, and surface water temperatures. The report is an update and addition to a previous report on the estuarine resources of FIIS (Bokuniewicz et al. 1993). This report also identifies work by Clark (2000) on dissolved trace metals found in surface waters within Great South Bay from 1998 to 1999.

The EPA STORET database (EPA 2012b) contains regional contaminant data pertinent to Long Island and FIIS. Two datasets include water-quality data for Long Island collected by the State of New York and NPS from four NY counties (Kings, Queens, Nassau, and Suffolk) and Monmouth County, NJ (see also *FIIS—Sediment contaminants*). One dataset includes sampling data dating from 1965 to 1989 containing approximately 55 points within or abutting the FIIS boundary[197] (EPA 2006). The second dataset, which covers sampling conducted from 1990 to 2005, includes nine sampling points within or abutting the FIIS boundary[197] (EPA 2006). Water-chemistry and water-quality data include salinity, water temperature, pH, alkalinity, color, specific conductance, Secchi disk depth, chlorophyll a, dissolved oxygen, total organic carbon, fecal coliform, total coliform, phosphorous, silicone, orthophosphate, phosphate, algae, nitrogen, nitrite, nitrate, ammonia, and total suspended solids. These regional data were downloaded from the EPA STORET database, converted to GIS, and organized in a geodatabase with associated metadata. The data resolution is fine enough for specific park use.

The Great South Bay Project is a hydrodynamic modeling program being conducted by the School of Marine and Atmospheric Sciences at SUNY Stony Brook. The project webpage displays hydrodynamic modeling results and presents physical observational data collected over a period of several years including: tidal averages, means, ranges, and mean transport streamlines; salinity measures; surface and bottom velocities; and depth averaged temperature graphs and maps (Flagg et al. 2011). Data are being collected from eight stations on the Great South Bay using SeaCat instruments measuring temperature and salinity. The instruments are deployed for as much as three months at a time. Temperature and salinity sensors have been deployed around the eastern portion of the Bay since 2004. Since 2010 some of these instruments have been enhanced to measure sea level, chlorophyll, and turbidity. Since mid-2010, real-time water temperature, salinity, chlorophyll-a fluorescence, and turbidity data has become available from an area known as the Smith Point bridge and a telemetering buoy deployed south of Sayville (at 40^{o} 41.6'N, 73^{o} 05.1'W). The goal of the Great South Bay program is to gain a thorough understanding of the biogeochemistry of the Bay and its effect on pelagic and benthic communities. Salinity measurements are a fundamental aspect of the model providing a tracer of water flow and dissolved elements throughout the system and potentially enabling the delineation of nutrient sources and sinks.

Submerged habitats and biological communities

Seagrass distribution

Maps of seagrass distribution in the South Shore Estuarine Reserve, including all FIIS estuarine waters within Great South Bay and Moriches Bay, were created from 2002 aerial photographs through a cooperative effort between the New York State Department of State and NOAA Coastal Services Center (NYS Seagrass Task Force 2009). The Northeast Coastal Barrier Network supported measurement of seagrass species composition, percent cover, and canopy height throughout FIIS in 2007 and 2009 (reported in Neckles et al. 2012).

A classification of SAV habitats within the FIIS park boundary was completed as part of a NPS funded project to develop a protocol for mapping terrestrial and submerged aquatic habitats using satellite imagery[153] (Wang and Traber 2008). FIIS SAV classification was completed using 2004 Quickbird-2 Satellite imagery, which was re-registered using 2002 base aerial orthophotography, and processed using ERDAS Imagine software. The data were created for the purpose of monitoring critical SAV habitat.

A digital version of eelgrass distributions published by Jones and Schubel (1980) provides maps showing percent by mass of eelgrass thoughout Great South Bay (see also *FIIS—Sediment grain size and organic content*). The data layer is published for inclusion in the usSEABED data collection.

Hinga (2005) focuses on the ecology of Great South Bay, particularly within FIIS boundaries[225]. The report provides a synthesis of seagrass studies and findings in Great South Bay, but does not incorporate distribution maps.

Estuarine habitats within Great South Bay were mapped and classified in 1996 by the University of Rhode Island[155] (Raposa and LaBash 1996). SAV habitat classes were interpreted and digitized from seventeen 1:7,200 scale, true-color aerial photographs that were collected for FIIS in 1992. The Field Evaluation of FIIS Estuarine Resources project was funded by the U.S. Department of Interior National Biological Service Coastal Research Center and the NPS North Atlantic Regional Office. The study area covers an area of FIIS measuring approximately 13.5 km by 1.2 km.

Macroalgae distribution
Hinga (2005) focuses on the ecology of Great South Bay, particularly within FIIS boundaries[225]. The report provides a synthesis of macroalgae studies and findings in Great South Bay, but does not incorporate distribution maps.

Biological communities and species inventories
As part of a pilot habitat mapping project, Schumchenia and King (2010) produced benthic community maps for two 1 km by 1.5 km study plots in Great South Bay based on interpretations of acoustic and ground-truth data (see also *FIIS—Bathymetry* and *Acoustic seabed characterization*). Goals of the project included evaluating methods to map and classify marine National Park habitats. Dominant species (SAV plus epifauna) and depth of sediment oxidation (aRPD depth) were interpreted from SPI images. Grain size was analyzed from sediment samples. These ground-truth data were used to determine if unique grain size and biotic groups exist within habitat units defined by acoustic signatures. In addition, ground-truth data were used to determine if groups of stations with similar grain size and/or dominant species possess unique acoustic properties. The study found that SAV and epifauna in this study area “greatly influence the acoustic response of the seafloor, and thus may be effectively mapped using acoustic tools” (Schumchenia and King 2010). Data from this study and from the NOAA Coastal Services Center were classified using CMECS III and an alternative classification system. Products include a benthic habitat map.

Conover et al. (2005) discuss the finfish species that use FIIS waters and benthic habitats for spawning, nursery, forage, and transient passage[226]. Also discussed are the types and status of shellfish species within FIIS boundaries.

Hinga (2005) focuses on the ecology and water quality of Great South Bay, particularly within FIIS boundaries[225]. Although the report does not provide taxa distribution maps, it provides a thorough synthesis of ecological studies and findings in Great South Bay, including information on shellfish, finfish, primary productivity, and habitat types. The report updates a previous report on FIIS estuarine resources (Bokuniewicz et al. 1993).

A study of the effects of barrier island breaches on biological resources in Great South Bay was conducted by NPS, New York Sea Grant, and the Marine Sciences Research Center at SUNY Stony Brook (Tanski et al. 2001). The partners initiated a project to assess how information supplied by geomorphic and hydrodynamic modeling could be used to evaluate potential changes to selected biological resources. The resulting report is a compilation of papers on the abundance and distribution of plankton, important shellfish, benthic habitats, benthic invertebrates, important SAV species, intertidal vegetation, and ecologically and economically important finfish, as well as the environmental parameters affecting these biological resources. The literature cited provides an extensive list of biological resource information available for the Long Island area.

Biogenic habitat created by sub-tidal relict oyster reefs is discussed within the results of a 2002 study within Great South Bay conducted by SUNY at Stony Brook (Clapp and Flood 2004; see also *FIIS—Acoustic seabed characterization*).

Digital benthic habitat maps of Long Island’s South Shore bays were created in 2003 from combined field observation data and scanned ortho-rectified photographs[154] (Greenhorne and O’Mara 2003). In 2002, the NYS Department of State's Division of Coastal Resources collected two hundred 1:20,000 scale conventional color film diapositives to map SAV in Long Island’s South Shore bays. The study area covered approximately 443 km^2 from the west end of Long Beach Island in Nassau County to Heady Creek at the east end of Shinnecock Bay in Suffolk County, with the large majority of the data falling within the FIIS boundary. Ground control points were collected from NYS Department of State 2-ft orthophotos. Elevations were derived from USGS digital elevation models. The NOAA Coastal Services Center and NYS Department of State staff collected and incorporated 95 field observations into the map in 2002. Eleven habitat types were delineated and classified from the combined data according to the System for Classification of Habitats in Estuarine and Marine Environments (SCHEME), with a minimum mapping unit (MMU) of 0.01 hectares. In 2003, the data were converted to ARCGIS format and assessed for horizontal spatial accuracy and thematic agreement. The horizontal accuracy of polygonal boundaries is estimated at +/- 5.5 m.

Estuarine habitats within Great South Bay were mapped and classified in 1996 by the University of Rhode Island[155] (Raposa and LaBash 1996). Eight SAV and saltmarsh habitat classes were interpreted and digitized from seventeen 1:7,200 scale, true-color aerial photographs that were collected for FIIS in 1992. The study area covers an area of FIIS measuring approximately 13.5 by 1.2 km.

The NPS Vegetation Mapping Program dataset for FIIS depicts the spatial distribution of vegetation associations for the entire length of Fire Island[156] (Klopfer 2002). Spatial distributions of vegetation on the park islands in Great South Bay are stored separately. Vegetation polygons were interpreted and delineated from 1:1200 scale, true-color aerial photographs taken in April 1997. In addition to classification delineations, the data include height, pattern, and density information. The final layer was converted to an ARCINFO coverage. Horizontal positional accuracy of the vegetation map was assessed at 47 points and the mean error distance was estimated to be 3.86 m (± 3.18 m) with a range of 0.00 m - 14.09 m.

Boston Harbor Islands National Recreation Areas (BOHA)
The Massachusetts Ocean Resources Information System (MORIS) is an online mapping tool that compiles geological, physical, and biological data for the Massachusetts coastal zone into an interactive geospatial database (MA CZM 2011). MORIS was created by the Massachusetts Office of Coastal Zone Management (MA CZM), the Massachusetts Office of Geographic Information (MassGIS), and a number of additional partners. MORIS is a primary source and compilation of data pertaining to CACO including bathymetry, hydrographic features, hydrography, surficial sediments, geologic framework, water quality, and biological data layers. Users can interactively view such data layers overlaid on aerial photographs or various basemaps.

The Official Website of the Office of Geographic Information (MassGIS 2012) includes a GIS database that houses all of Massachusetts digital GIS data. The database and datalayers include aerial photography, topographic reference maps, surficial geology basemaps, elevation data, digital elevation models, coastal and marine features data (including MORIS layers, beaches, tidelands, fish and shellfish, wetlands, etc.), rare species and protected habitats, environmental monitoring, soils, hydrography, and other relevant data.

Bathymetry
National, regional, and localized datasets provide bathymetric information at varying resolutions for all submerged areas within BOHA boundaries. The following data descriptions represent the existing local and park-specific bathymetric datasets available for BOHA at the time of the inventory's completion, as well as a number of additional bathymetry datasets acquired post-inventory. Descriptions of national and regional datasets relevant to BOHA are included in the *National and Regional Datasets* section.

Two Gulf of Maine coverages pertaining to BOHA are described in the *National and Regional Datasets—Bathymetry* section (Banner 2002; MassGIS 1999).

The NOAA Estuarine Bathymetry Project website[234] features localized bathymetric coverage for BOHA in the form of 3-arc-second (about 90 m) and 30-m resolution digital raster compilations[234] (NOAA 2007). Bathymetry for Massachusetts Bay, encompassing BOHA, was derived from 38 hydrographic surveys conducted by the NOAA National Ocean Service (NOS) from 1940 to 1970 (NOAA NOS 1998b). Combined the surveys contain 297,628 soundings with an average separation of 57 m and covered depths from 3 m above to 71 m below mean low water. Massachusetts Bay has fifteen 7.5-minute digital elevation models (DEMS) and two 1-degree DEMs. Vertical accuracy of the bathymetric DEMs is estimated at 2% of depth (or 1 m for depths greater than 20 m and 0.20 m for depths shallower than 20 m).

In 2008, the Massachusetts Office of Coastal Zone Management (MA CZM) published a 30-m resolution mosaic of bathymetric datasets for all waters off the coast of Massachusetts, derived from "the most current and accurate sources"[236] (Figure 14; MA CZM 2008). The mosaic is a compilation of bathymetric data varying in resolution from 2 m to 90 m including USGS Open-File Reports, the NOAA Estuarine Bathymetry Project[234] (NOAA 2007), the NOAA NGDS Coastal Relief Model for the Northeast (NOAA NGDC 1999b), and other sources. The data were developed to form a continuous bathymetric model for Massachusetts waters, covering the entire geographic extent with no known omissions.

Specific to Boston Harbor and its approaches, 2-m multibeam bathymetry grids were developed covering the navigation channels that lie between the Harbor Islands and approximately 450 site-specific locations that were identified as potential hazards to navigation[228] (Ackerman 2006). The data were collected over the course of four NOAA NOS hydrographic surveys conducted in 2000 and 2001 (NOAA Hydrographic Survey H10990, H10991, H10992, and H10994). High-resolution multibeam bathymetry measurements were acquired over a 65-km^2 area using a Reson SeaBat 8101 multibeam echosounder operating at 240 kHz, with a horizontal range of 75 m to 500 m (Ackerman et al. 2006). The multibeam bathymetry data span approximately 37% of the full survey area and near the park boundaries of a number of BOHA managed islands. In addition to multibeam bathymetry, the surveys acquired single-beam bathymetry over an area of approximately 170 km^2. The single beam data overlap with the boundaries of a number of BOHA islands. Sidescan sonar backscatter data were also acquired during the surveys over a 155-km^2 area of the Harbor and its approaches (see *BOHA—Seabed characterization*). In 2004, USGS and MA CZM created 2-m bathymetry grids from these data from a Caris HIPS database processed and transferred by the NOAA Office of Coast Survey. USGS and MA CZM also created a composite bathymetry grid from these data at a 30 m/pixel resolution (Ackerman et. al. 2006). The associated open-file report includes maps of the seafloor at a scale of 1:25,000 and the data in GIS format. The data are also available as raster digital information within MORIS.

These data improve upon formerly available bathymetry data pertaining to BOHA, including a bathymetric dataset for Boston Harbor channels created for the NPS in 2001 by MassGIS and the Environmental Data Center at the University of Rhode Island (URI EDC)[2] (MassGIS and URI EDC 2001). These bathymetry data were digitized from NOAA nautical chart #13270 and cover major dredged channels deeper than about 9 m. These data provide a course demarcation of channel boundaries and contours. None of the data fall within BOHA park boundaries.

The NOAA Coastal Services Center published coastal topographic and bathymetric lidar survey data for Maine, Massachusetts, and Rhode Island (NOAA CSC 2009; see also *National and Regional Datasets—Bathymetry*). The survey footprint and metadata (2009) can be viewed on the NOAA Coastal Services Center Digital Coast Data Access Viewer (NOAA CSC 2012).

<u>Hydrography</u>

Wave height, direction, and periodicity

There are two monitoring stations providing data relevant to wave height, direction, and periodicity at BOHA (Figure 26, Table 10, NOAA NWS 2012b). Buoy 44013 (LLNR 420, Boston), owned and operated by NOAA's National Data Buoy Center, is approximately 19 km east of Boston, MA. Buoy 44029 (A0102, Mass. Bay/Stellwagon), operated by the Northeastern

Regional Association of Coastal Ocean Observing Systems (NERACOOS 2012), is located about 25 km east of Salem, MA, about 40 km northeast of BOHA.

Tide range, phase, and currents

Tide data relevant to BOHA are collected at NOS Station 8443970 (BHBM3, Boston, MA) and USGS Station 01104715, both in Boston, MA (Table 10, Figure 26, NOAA NOS 2011, USGS 2012b).

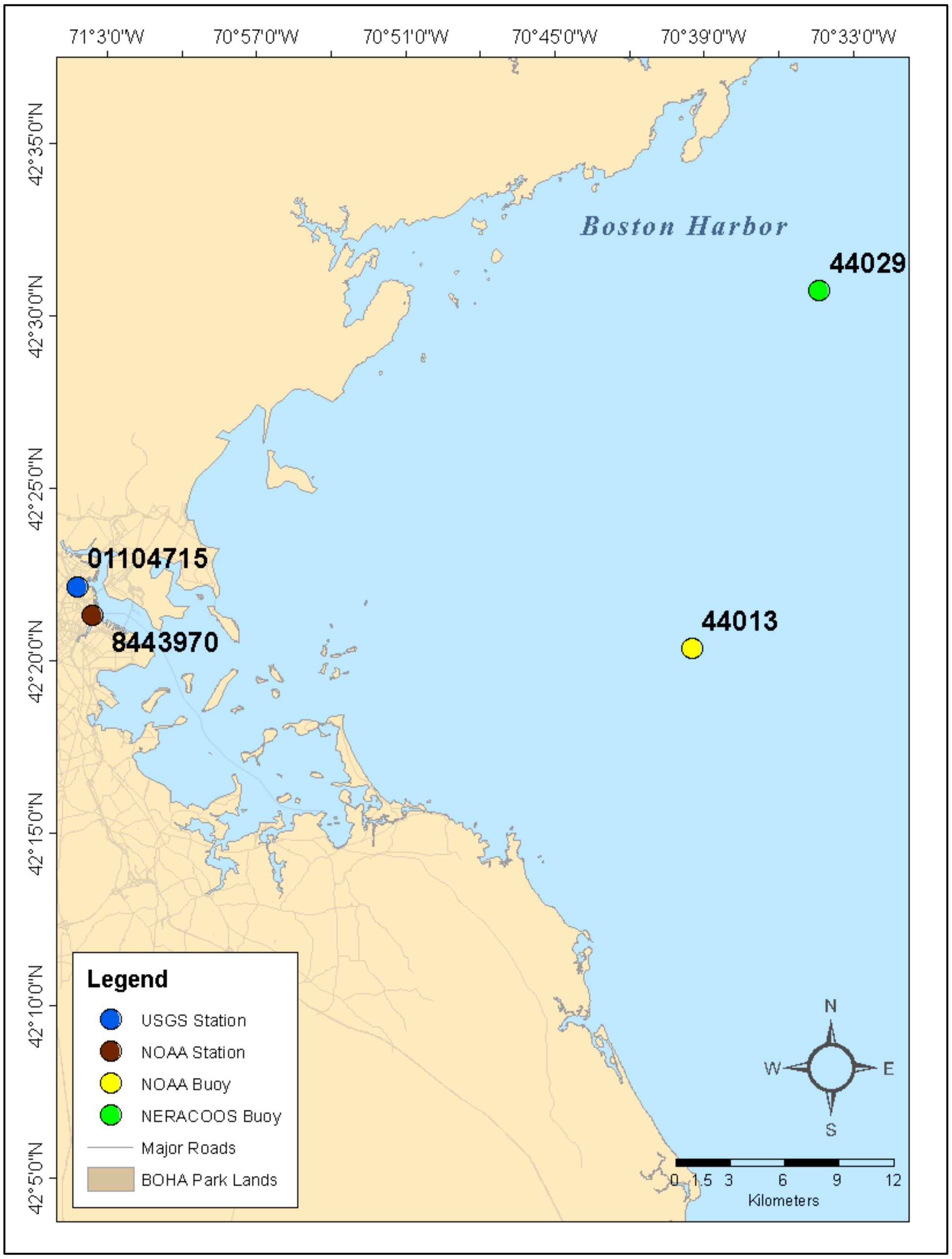

Figure 26. Hydrographic data monitoring stations in the vicinity of Boston Harbor Islands National Recreation Area (NERACOOS 2012, NOAA NOS 2011, NOAA NWS 2012b, USGS 2012b).

Table 10. Hydrographic monitoring data collected in the vicinity of Boston Harbor Islands National Recreation Area (NERACOOS 2012, NOAA NOS 2011, NOAA NWS 2012b, USGS 2012b).

BOHA	**NOAA NOS Station**	**NOAA NDBC Moored Buoy**	**NERACOOS Moored Buoy**	**USGS Station**
Station Name	**BHBM3**	**LLNR 420**		
Station Code	**8443970**	**44013**	**44029**	**01104715**
Wind Direction	-	+	+	-
Wind Speed	-	+	+	-
Wind Gust	-	+	+	-
Wave Height	-	+	+	-
Dominant Wave Period	-	+	+	-
Average Period	-	+	-	-
Mean Wave Direction	-	-	-	-
Atmospheric Pressure	+	+	+	-
Pressure Tendency	-	+	+	-
Air Temperature	+	+	+	-
Water Temperature	+	+	+	-
Dew Point / Relative Humidity	-	-	-	-
Water Level	+	-	-	+
Conductivity/Salinity	-	-	+	-

Hydrogeologic framework

Surface and groundwater pathways

In addition to localized sources below, data on surface-water level, stream flow, and groundwater level are provided by the USGS National Water Information System (USGS 2012b, see *National and Regional Datasets—Hydrogeologic framework*).

In 1996, USGS conducted an investigation of the geohydrology, groundwater flow, and potential for developing water supplies for six of the Boston Harbor islands including Bumpkin, Gallops, Georges, Grape, Lovell and Peddocks islands (Masterson et al. 1996).

A study by Menzie et al. (1991) conducted for the Massachusetts Water Resources Authority estimated groundwater discharges and loadings of various substances (nutrients, metals, organic contaminants) to Boston Harbor.

Flora et al. (2002) discuss ground water resources in the park as well as other resources (see also BOHA—*Biological communities and species inventories, Water quality,* and *Hydrogeologic framework).*

Bedrock geology and shallow stratigraphy

USGS published data from seismic-reflection profiles (as well as sidescan-sonar images, sediment cores, and surficial sediment samples) that were collected to outline the shallow stratigraphy and surficial sediments of the Boston Harbor estuary (Knebel et al. 1992; see also

BOHA—Acoustic seabed characterization). Seismic-reflection profiles extended to a maximum of 35 m below the Harbor floor.

The NPS Geologic Resources Inventory (GRI) Scoping Report for BOHA provides a list of existing surficial and bedrock geology maps with coverage relevant to the park (*see National and regional Datasets—Hydrogeologic framework*). Surficial and bedrock geologic maps were identified to provide broad scale coverage, but the resolution may be too coarse for certain resource management needs. Scoping meeting participants identified forthcoming products that might fill the gaps in existing coverages, but identified a potential need for new acquisition of digital data of both the bedrock and surficial geology for parts of the BOHA area.

<u>Surficial geology</u>

Acoustic seabed characterization

NOAA NOS acquired sidescan sonar data, in conjunction with multibeam bathymetric data, over an area of approximately 155 km² of Boston Harbor and its approaches during four hydrographic surveys conducted in 2000 and 2001 (see also *BOHA—Bathymetry*). The data were acquired with Edgetech model 272-T (100 kHz) or Klein T-5500 (455 kHz) sidescan sonar systems. In an effort to identify all hazards to navigation, sidescan surveys were overlapped to ensure 100% coverage of the seafloor over most of the survey area. Bottom photographs, video, and sediment samples were collected in September 2004 for interpretation and ground-truthing of the geophysical data. The raw data were reprocessed and gridded by MA CZM and USGS in 2006[228] (Figure 27; Ackerman et al. 2006). Sidescan-sonar data were mosaicked and exported as 1 m/pixel resolution TIFF image files. The data are also available as raster digital information within the MORIS database. High-resolution maps of the seafloor at a scale of 1:25,000 depict backscatter intensity, shaded-relief topography colored by backscatter intensity, and seafloor geology. The spatial extent of the data overlaps with small portions of three BOHA islands, and abuts the boundaries of a number of others.

Knebel et al. (1992) published data from sidescan-sonar images, seismic-reflection profiles, sediment cores, and surficial samples that were collected by USGS to outline the shallow stratigraphy and surficial sediments of the Boston Harbor estuary.

Sediment grain size and organic content

Sediment grain size and organic content data for BOHA consists of national and regional datasets such as EPA's NCA and NARS, CONMAP, usSEABED (two points within park boundaries), the USGS Marine Aggregate Resources Project, and the East Coast Sediment Texture Database (with over a dozen points in BOHA) (see *National and regional Datasets—Sediment grain size and organic content*). A number of more localized datasets are included in the inventory and several additional park-related resources have been located during the writing of this report.

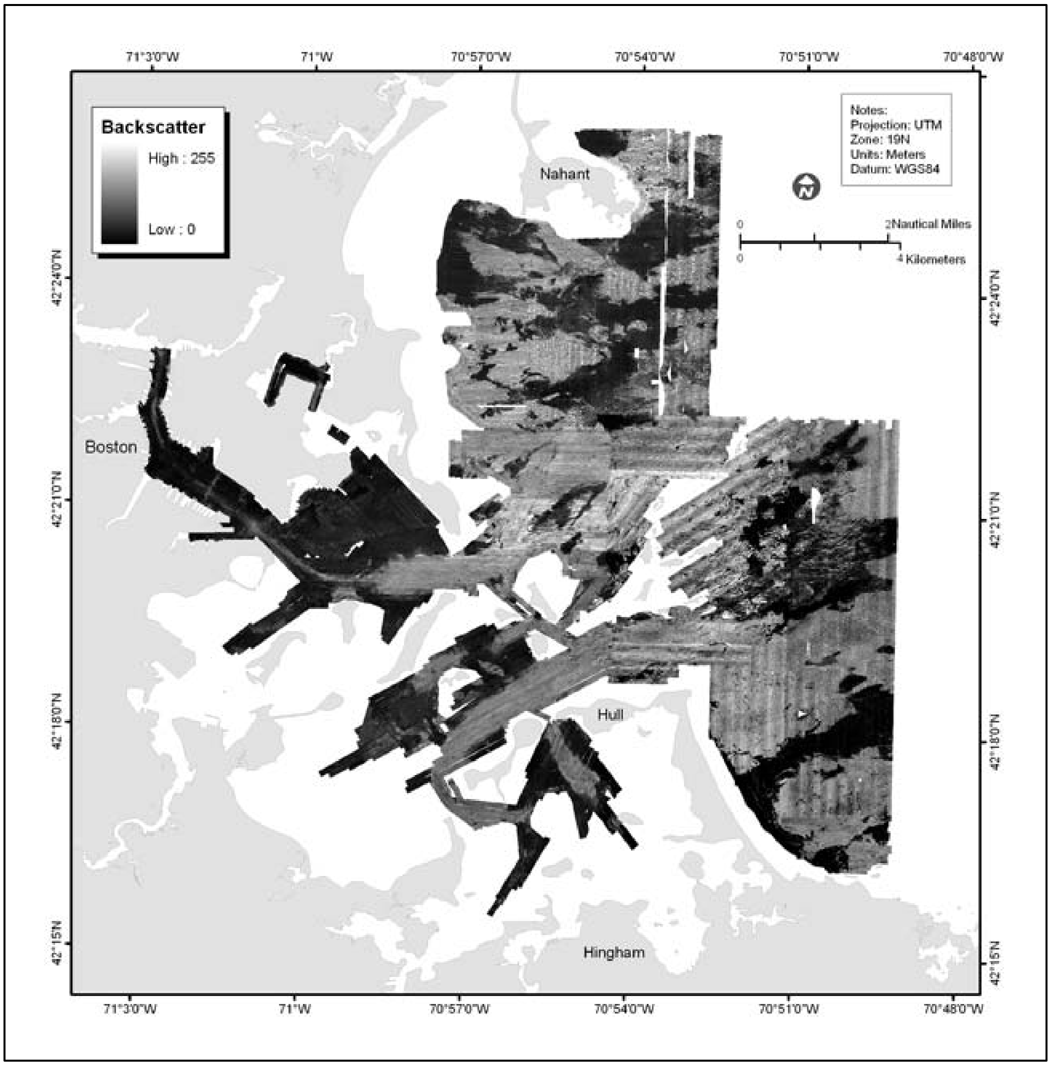

Figure 27. Map showing mosaic of sidescan-sonar data of the survey area Boston Harbor and Approaches, Massachusetts (Ackerman et al. 2006).

USGS and partners compiled a map specific to Boston Harbor derived from datasets identified in the USGS's National Benthic Habitats and Marine Aggregate Resources and Processes Projects (Poppe et al. 2003). Several sediment data sources relevant to BOHA are incorporated into the Boston Harbor GIS compilation:

(1) In 1968, USGS collected grab samples from 152 sampling stations in Boston Harbor to study composition, grain size distribution, and organic content[35] (Mencher et al. 1968). None of the sample stations fall directly within BOHA park boundaries, although a number are in near proximity;

(2) From 1993 to 1995, the Massachusetts Water Resources Administration collected and analyzed textural distributions in surficial sediment samples to study the effects of the Boston sewage outflow[36]. The data layer digitizes the findings of four studies (Blake et al. (1993), Coats (1995), Coats et al. 1995, and Kropp and Diaz (1995) (see also *BOHA—Sediment Contaminants*). None of the sample stations fall directly within BOHA park boundaries;

(3) a clipped version the Smithsonian Institution Master Sediment data file, which contains information from archival samples submitted by various entities from 1965 to 1990 for the Gulf of Maine, Georges Bank, and southeastern New England (Poppe et al. 2003);
(4) NOS hydrographic sampling data from 1869 to 1985 and NOS cartographic codes for bottom characteristics that are no longer readily available for interpretation of surficial sediment distributions. Numerous sample sites fall within 1 km of BOHA;
(5) textural data from CONMAP and the East Coast Textural Database; and
(6) a 1972 sediment survey of Boston Harbor and its approaches.

The Contaminated Sediments Database for the Gulf of Maine provides a synthesis of existing sediment data to aid analyses of environmental status, contaminant transport paths, and the fate of contaminants[43] (Buchholtz ten Brink et al. 2002). This database is the product of collaboration between principal investigators from USGS, Woods Hole Oceanographic Institution, the University of New Hampshire, Bigelow Laboratory for Ocean Sciences, the University of Massachusetts, and participants from the U.S. Army Corps of Engineers, EPA, NOAA, the Massachusetts Water Resources Authority, and other federal and state agencies. A subset of the database, released in 2002, is intended to aid interpretations of surficial sediment distribution off of the northeastern U.S. The datalayer contains grain size data from 852 points in the coastal waters of Massachusetts, Maine, and New Hampshire. Approximately 500 of these points fall within Boston Harbor, but none are directly within park boundaries[43]. Similarly, the Texture Table in the Gulf of Maine Database contains grain size information from over 4000 samples collected throughout the northeastern U.S., with some points located in the vicinity of the Boston Harbor islands (Buchholtz ten Brink et al. 2002). This report includes a coarse map of sediment-type distributions in Boston Harbor.

<u>Sediment contaminants</u>
Sediment contaminant data collected in the vicinity of BOHA are included in EPA's NCA and NARS (*see National and Regional Datasets—Sediment contaminants*), as well as the following localized data sets.

The Contaminated Sediments Database for the Gulf of Maine[43] (Buchholtz ten Brink et al. 2002) provides a synthesis of existing sediment data to aid analyses of environmental status, contaminant transport paths, and the fate of contaminants. The database is a compilation of existing, edited data on contaminated sediments and related sediment properties. The database integrates many sources into a regional database and provides a review of data quality. The database is the product of collaboration between principal investigators from USGS, Woods Hole Oceanographic Institution, the University of New Hampshire, Bigelow Laboratory for Ocean Sciences, the University of Massachusetts, and active participation from the U.S. Army Corps of Engineers, NOAA, MWRA, and other federal and state agencies. Contaminant data within the database include information on 35 major/minor/trace elements, 40 other inorganic parameters, and organic parameters.

<u>Water chemistry and water quality</u>
Water-chemistry and water-quality data for BOHA consist of national/regional datasets (see *National and regional Datasets*) as well as the following localized data sets.

Flora et al. (2002) discuss water quality studies conducted within the park as well as other park resources (see also BOHA—*Biological communities and species inventories, Seagrass distribution,* and *Hydrogeologic framework).*

The Massachusetts Water Resources Authority (MWRA) monitors water quality at more than 50 locations in Boston Harbor[90]. The monitoring is designed to assess the impacts of combined sewer overflows on the harbor and measures nutrients, pathogens, metals, organics, solids, pH, oil and grease, and toxicity (MWRA 2012). The monitoring stations are distributed throughout Boston Harbor and are highly relevant for BOHA.

<u>Submerged habitats and biological communities</u>

Seagrass distribution

The Massachusetts Department of Environmental Protection's Wetlands Conservancy Program (MassDEP-WCP), Massachusetts Office of Coastal Zone Management (MA CZM), and the NOAA Coastal Services Center's Coastal Change Analysis Program (CCAP) developed a baseline digital map of submerged aquatic vegetation (SAV) in coastal Massachusetts from 1993 to 1997[131] (MassDEP and NOAA CSC 1998). The survey utilized protocol developed by CCAP. The data were classified according to the System for Classification of Habitats in Estuarine and Marine Environments (SCHEME) developed in Florida. The program produced six digital coverages of SAV along the entire Massachusetts coast from interpretation of 1:20,000 scale color metric aerial photography collected from 1994 to 1996. The aerial photography for Boston Harbor was acquired in 1996 by the James W. Sewall Company. MassDEP-WCP delineated SAV polygons and conducted field ground-truthing (videography) to develop signatures and delineate habitats that were not readily apparent in the photography. An assessment of accuracy found that 175 of the 205 sites (85.4%) were mapped correctly.

Newer SAV data for BOHA (and CACO) were acquired by MassDEP-WCP in 2001[132] (Figure 18; MassGIS 2010). Eelgrass beds were delineated from 1:12,000 scale aerial photographs acquired from 1999 to 2001. The imagery was ortho-rectified at a resolution of 1 m with 90% of the pixels accurate to within 3 m. Photos signatures were interpreted by visual evaluation and polygons were drafted. Field groundtruthing was conducted to verify the photosignatures. These MassDEP statewide eelgrass polygons were developed in order to determine change in eelgrass coverage since mapping in the 1990s. An accuracy assessment of the digital product showed that 85.4% of the beds had been mapped correctly. The MassDEP eelgrass layer has been updated to include data from 2006/2007 and 2009/2010. Costello and Kenworthy (2011) summarized statewide changes in eelgrass distribution during a twelve-year mapping interval. In addition, an online viewer is available for Massachusetts eelgrass maps (MassDEP 2012).

Flora et al. (2002) discuss SAV distribution and change within the park (see also BOHA—*Biological communities and species inventories, Water quality*, and *Hydrogeologic framework).*

Also of use for SAV mapping and other purposes, North Carolina State University created an orthorectified color infrared image of BOHA from 41 color infrared photos taken in 2003 (NCSU 2005). The positional accuracy for the photomosaic is 5.87 m. The data were developed for BOHA for digital monoplotting and mapping.

Biological communities and species inventories

The Mass DEP Wetlands Conservancy Program has mapped the state's wetlands using aerial photography and photointerpretation to delineate wetland boundaries. The wetlands are interpreted from 1:12,000 scale, stereo color-infrared (CIR) photography by staff at the university of Massachusetts (UMass) Amherst. The photography was captured in 1990, 1991, 1992, 1993, 1999 and 2000. Wetland type was coded according to USFWS classification. Photo interpretations were field checked by the MA DEP Wetlands Conservancy Program (WCP).

Completed interpretations are then scanned and converted into rectified polygons and lines using standard photogrametric techniques. Wetland maps for area within BOHA can be accessed through the Massachusetts online data viewer (MassGIS 2011a). In 2007 polygons and arcs of wetland environments within the three watersheds bordering Boston Harbor were created[130] (MassDEP 2007).

In the fall of 2002, MassDEP launched the Wetlands Change Project, an evaluation of wetland protection efforts in the state over the previous decade via remote sensing and GIS-based data analysis[133] (MassGIS 2011b). This project utilized state wetlands maps produced Mass DEP-WCP over 11 years through interpretation of aerial photography. The project used the 1:12000 DEP Wetlands datalayer, covering 70% of the state by 2002, to develop a digital database of wetland alterations made from 1990 to 2001. Later aerial imagery was superimposed on base wetland maps to assess changes over time. The datalayer currently comprises three polygon feature types, wetlands change from 2001/2003 imagery, wetlands change from 2005 imagery, and wetlands change from 2008/2009 imagery. The attribute codes in the polygon layer describe different types of wetland environments and different types of reasons for the wetlands change.

Flora et al. (2002) discuss wetland habitat mapping and wetland status in the park. This report also discusses recent trends in benthic infaunal communities and habitats; fish and shellfish indicators of water quality; critical wetland, intertidal, and SAV resources; and ground water resources in the park (see also BOHA—*Seagrass distribution, Water quality,* and *Hydrogeologic framework).*

In 2002, baseline intertidal mapping was completed by the New England Aquarium, University of Rhode Island, and Massachusetts Audubon Society on 20 of the 34 islands within BOHA[129] (Bell et al. 2002). The intertidal areas of the remaining 14 islands within the park were mapped in 2003. The complete intertidal area of the islands was delineated by walking the perimeter of each substrate and assemblage type with a Trimble GeoExplorer III GPS unit. Thirteen substrates and 31 assemblages were classified on these islands according to the Boston Harbor Intertidal Classification System[129] (BHICS; Bell et al. 2002). Intertidal area for the park system was calculated from the spatial data. This intertidal inventory was completed to provide a means for measuring and tracking anthrogenic-induced change. Horizontal and vertical accuracy of the data was defined by a Max PDOP value of 5.0 and minimum satellite angle of 15 degrees.

The Massachusetts Division of Marine Fisheries (DMF) established approximately 2700 sampling stations as of July 2000 as part of the DMF Shellfish Project[134] (MA DMF 2000a). Approximately 15 of the stations overlap with BOHA boundaries, with numerous other stations nearby. The stations include sites for collecting water quality, shellfish, and marine biotoxin (PSP) samples, as well as locations of marinas and mooring fields. The sampling locations are stored as the SHLFSHST point coverage in the New England library and as SHLFSHST_PT in the ArcSDE. Each station is associated with a designated shellfish growing area, which is described in a separate datalayer[139] (MA DMF 2000b). The Designated Shellfish Growing Areas datalayer contains areas designated by MA DMF as potential shellfish habitat. Metadata provided by MassGIS for both datalayers are not FGDC-compliant.

The Shellfish Suitability Areas datalayer was developed by MA DMF in collaboration with MA CZM and NOAA CSC[138] (MA DMF, MA CZM, and NOAA CSC 2011). The polygons within this datalayer represent hand-drawn boundaries of locations that are believed to be suitable habitats for 10 shellfish along the Massachusetts coast. The species include the American oyster, bay scallop, blue mussel, European oyster, ocean quahog, quahog, razor clam, sea scallop, soft-shelled clam, and surf clam. The polygons include both current and historic shellfish sites and are based on information from MA DMF, Massachusetts shellfish constables, studies of shellfish, and maps. The shellfish suitability areas were not field-checked, nor were boundaries surveyed. The Shellfish Suitability Areas were hand-drawn on DMF Designated Shellfish Growing Areas base maps or NOAA Nautical Charts, digitized, and then converted into an ArcInfo coverage. Blue mussel, soft-shelled clam, and European oyster suitability areas abut or marginally overlap with the boundaries of approximately 19 of the BOHA islands.

MassGIS, MA DMF, and the Massachusetts Division of Fisheries and Wildlife developed a point coverage of all known coastal anadromous fish runs and spawning habitat for three major inland rivers[135] (MA DFW 1997). Interviews with DMF biologists were used to compile data points onto 1:25,000-scale basemaps using the best available hydrographic data. The dataset includes the ANADFISH shapefile and seven related tables stored in the New England library. The layer is also stored in ArcSDE as ANADFISH.

The Natural Heritage and Endangered Species Program (NHESP) database includes the Priority Habitats of Rare Species datalayer, with polygons showing the geographic extent of habitats for state-listed rare species[137] (MA NHESP 2008). The datalayer is based on observations of rare species documented over a 25-year period concluding in 2006. The habitat polygons were heads-up digitized in ArcView at a 1:25,000 scale and referenced to MassGIS's 2001 Color Orthophotos. Priority Habitats were digitized by NHESP scientists from documented observations of rare species and are based on such factors as species movements and habitat requirements. A large percentage of BOHA is included within a Priority Habitats polygon.

An Environmental Sensitivity Index atlas has been developed for the Massachusetts coastal zone by the NOAA Office of Response and Restoration, NOAA Coastal Services Center, and the Massachusetts Executive Office of Environmental Affairs (MA EOEA)[140] (NOAA 1999). The atlas was developed following the structure and format of ESI's developed for U.S. shorelines (see *National and Regional Datasets*). The ESI atlas for Massachusetts includes digital data, a report, and PDF maps that characterize marine and estuarine environments and wildlife according to their sensitivity to oil spills. NOAA (1999) describes the methods and data sources used to collect comprehensive data on Massachusetts shoreline habitats, sensitive biological resources, and human-use resources. Digital data files relevant to BOHA include biological sensitivity information for birds, fish, anadromous fish, mammals, reptiles, nesting locations, and breeding locations; human resource information such as historic sites; and baseline information including shoreline descriptions, salinity distributions, socioeconomic conditions, and environmental status.

Acadia National Park (ACAD)

Bathymetry

Descriptions of national and regional bathymetry datasets relevant to ACAD are included in the *National and Regional Datasets* section. The following data descriptions summarize localized datasets recorded in the inventory for ACAD.

The NOAA Estuarine Bathymetry Project website[234] (NOAA 2007) features localized bathymetric coverage for ACAD in the form of 3-arc-second (about 90 m) and 30-m resolution digital raster compilations (NOAA NOS 1998g). Bathymetry for Bar Harbor was derived from fourteen surveys containing 155,591 soundings dating from 1946 to 1962 in depths to 214 m below mean low water. The average separation between soundings was 108 m. Bar Harbor has twenty-five 7.5-minute DEMs and four 1-degree DEMs. Vertical accuracy of the bathymetric DEMs is estimated at 2% of depth (or 1 m for depths greater than 20 m and 0.20 m for depths shallower than 20 m).

Two Gulf of Maine coverages pertaining to ACAD (as well as BOHA, SAIR, and CACO) are described in the *National and Regional Datasets* section (Banner 2002; MassGIS 1999).

In 1999, the Maine Geological Survey (ME GS) developed 10-m interval bathymetry contours for the northern portion of the Gulf of Maine using USGS 30-minute by 60-minute series topographic-bathymetric maps, based on data from 1956 to 1983[221] (ME GS 1999). The metadata states that the dataset, at a scale of 1:100,000, is suitable for planning studies at the regional level and not intended for use in navigation. Approximate horizontal positional accuracy is 51 m.

In 2005, researchers working in conjunction with the Maine Geological Survey reported on a 10-year GIS compilation of data from seafloor surveys conducted in the western Gulf of Maine[216] (Kelley et al. 1998). The 1:100,000 map series compiles data collected for a variety of projects and therefore contains varying degrees of geophysical data and bottom sample coverage from place-to-place (ME GS 2010; see also *ACAD— Bedrock geology and shallow stratigraphy; Acoustic seabed characterization;* and *Sediment grain size and organic content*). A series of seven maps provide a broad overview of seafloor bathymetry (and bottom types) along the coast of Maine. Topography for ACAD is included in maps that display data from Rockland to Bar Harbor[218] (Barnhardt et al. 1996a) and Mt. Desert Island to Jonesport[219] (Barnhardt et al. 1996b). The report that accompanies the map series (Kelley et al. 1998) explains field data collection techniques and describes the seafloor of the area.

The NOAA Coastal Services Center published coastal topographic and bathymetric lidar survey data for Maine, Massachusetts, and Rhode Island (NOAA CSC 2009; see also *National and Regional Datasets—Bathymetry*). The survey footprint and metadata (JALBTCX 2009) can be viewed on the NOAA Coastal Services Center Digital Coast Data Access Viewer (NOAA CSC 2012).

Hydrography

Wave height, direction, and periodicity

Wave height and periodicity in the vicinity of ACAD are monitored at one buoy, 44034 (I0103, Eastern Maine Shelf), operated by NERACOOS (Figure 28, Table 11; NERACOOS 2012). This buoy is located about 13 km southeast of Little Duck and Great Duck Islands, ME. An additional station farther south (MDRM1) collects wind data (Figure 28, Table 11, NOAA NWS 2012b).

Figure 28. Hydrographic data collection stations in the vicinity of Acadia National Park (NERACOOS 2012, NOAA NOS 2011, NOAA NWS 2012b).

Table 11. Hydrographic data collected in the vicinity of Acadia National Park (NERACOOS 2012, NOAA NOS 2011, NOAA NWS 2012b).

ACAD	NOAA NDBC Fixed Station	NOAA NOS Station	NERACOOS Moored Buoy
Station Name	**MDRM1**	**ATGM1**	**I0103**
Station Code		**8413320**	**44034**
Wind Direction	+	+	+
Wind Speed	+	+	+
Wind Gust	+	+	+
Wave Height	-	-	+
Dominant Wave Period	-	-	+
Average Period	-	-	-
Mean Wave Direction	-	-	-
Atmospheric Pressure	+	+	+
Pressure Tendency	+	-	+
Air Temperature	+	+	+
Water Temperature	-	+	+
Dew Point	+	-	-
Water Level	-	+	-
Conductivity/Salinity	-	-	+

Tide range, phase, and currents

Real-time tide data near ACAD are collected at NOAA NOS 8413320 (ATGM1) located 1 km south of Bar Island on the north side of Bar Harbor in close proximity to the park (Figure 28, Table 11, NOAA NOS 2011).

Hydrogeologic framework

Surface and groundwater pathways

In addition to localized sources below, data on surface-water level, stream flow, and groundwater level are provided by the USGS National Water Information System (USGS 2012b, see *National and Regional Datasets—Hydrogeologic framework*).

The Maine Geologic Survey's Bedrock Ground-water Resources Program compiles information on bedrock wells drilled by commercial well-drillers. Various maps of ground-water resources on Mt. Desert Island are relevant to ACAD, including overburden thickness (Tolman 2010a), well yield (Tolman 2010b), and well depths (Tolman 2010c). In addition, significant aquifer maps portray water-bearing sand and gravel aquifers (scale 1:24,000) within USGS topographic quadrangles (e.g., Locke and Neil 2007).

Bedrock geology and shallow stratigraphy

The NPS Geologic Resources Inventory Scoping Report for ACAD identifies existing sources of surficial and bedrock geologic maps for the Mt. Desert Island portion of ACAD (*see National and regional Datasets—Hydrogeologic framework*). Scoping meeting participants determined that geologic mapping coverage for the Schoodic Peninsula and Isle au Haut portions of ACAD still needed to be completed and identified likely sources of detailed geologic information. Participants also stressed that mapping of submerged marine resources beyond the park boundary is important so that potential impacts to the park from offshore development may be addressed; for the purpose of our report, this need is considered within sections on *Bathymetry* and *Surficial geology*. The GRI Report and accompanying digital geologic map for ACAD includes the Mt. Desert Island portion only (Graham 2010).

In 2005, researchers working in conjunction with the Maine Geological Survey reported on a 10-year GIS compilation of data from seafloor surveys conducted in the western Gulf of Maine[216] (Kelley et al. 1998; see also *ACAD—Bathymetry; Acoustic seabed characterization;* and *Sediment grain size and organic content*). The 1:100,000 map series compiles data from a variety of projects and therefore contains varying degrees of geophysical data and bottom sample coverage from place-to-place (ME GS 2010). A series of seven maps provide a broad overview of seafloor bottom types (and bathymetry) along the coast of Maine. The maps that incorporate ACAD include topography, surficial sediments, geomorphology, and bedrock data from Rockland to Bar Harbor[218] (Barnhardt et al. 1996a) and Mt. Desert Island to Jonesport[219] (Barnhardt et al. 1996b). The report that accompanies the map series (Kelley et al. 1998) explains field data collection techniques and describes the seafloor of the area. Seismic reflection profile data within the compilation consist of 5,011 km of tracklines along the Maine coast surveyed with a Raytheon RTT 1000a 3.5/7.0-kHz seismic reflection profile unit in relatively shallow waters and muddy bottoms, and with an ORE Geopulse "boomer" seismic system in deeper waters or sandy or gravelly sediment. The seismic reflection profiles were used to construct the geologic history of the area, as well as to identify bathymetry and surficial sediment deposits. When combined with sidescan sonar images, seismic reflection profile data were used to characterize and age surficial sediments. Figures are included in the report to describe the seismic facies existing in the western Gulf of Maine.

Incorporated within the compilation of data for the Gulf of Maine inner continental shelf (see above) is a 1991 report on the seafloor geomorphology, surficial sediments, and stratigraphy in the vicinity of Blue Hill and Frenchman Bays[217]), an area encompassing ACAD (Barnhardt and Kelley 1991). The study covered 490 km of seafloor from the nearshore out to 100 m, focusing on areas of the seafloor where no similar data had been collected previously. Data were collected via seismic reflection profile surveys conducted from 1989 to 1990 using ORE Geopulse “boomer” and EG&G “boomer” systems. These seismic profile data were used in conjunction with sidescan sonar and bottom sampling groundtruth data to interpret surficial sediment types and to interpolate between bottom samples (see *ACAD—Acoustic seabed characterization* and *Grain size and organic content*). Subbottom geology was interpreted from the seismic data based on land observations and previous core samples where available. The report describes a number of previous seismic and bottom sampling surveys relevant to ACAD including: seismic stratigraphy surveys and coring in Penobscot Bay (Ostericher 1965; Knebel 1986) and bottom sediment mapping in Somes Sound (Folger et al. 1972).

The BEDROCK series provides maps of Maine bedrock geology and major faults at a scale of 1:500,000. The series is a digitized representation of a 1985 paper map of Maine bedrock geology[223] (Osberg et al. 1985), which extends partially into the submarine environment. The digitized dataset was developed in 1987 by the Maine Geological Survey, with funding from the

U.S. Department of Energy. Bedrock UNIT codes were added to the dataset in 1990 and 1994. A digitized version of the 1985 Surficial Geologic Map of Maine is also available as a result of this effort (Marvinney and Loiselle 2003).

Surficial geology

Acoustic seabed characterization

Sidescan sonar data were compiled as part of a Maine Geological Survey report and GIS compilation of data from pre-2000 seafloor surveys conducted in the western Gulf of Maine[216] (Kelley et al. 1998). The 1:100,000 map series compiles data from a variety of projects and therefore contains varying degrees of geophysical data and bottom-sample coverage from area to area (ME GS 2010). The maps in the series provide a broad overview of seafloor bathymetry and bottom types along the coast of Maine. Analog side-scan sonar records along 3,358 km of the seafloor were gathered coast-wide with an EG&G Model 260 slant-range corrected device operating with a Model 272-T towfish at a nominal frequency of 105 kHz. Side-scan sonar records were interpreted with the aid of ground-truth information from thousands of bottom samples taken between 1984 and 1991 and over 50 submersible dives. Surficial geologic maps were prepared by overlaying side-scan sonar information on bathymetry maps that were derived from 10-m contour interval, digitized NOAA bathymetric charts. Textural information was interpreted from the original side-scan sonar records. In areas where there were no overlaps of the sidescan sonar lines, surficial geology was interpolated using bathymetry, bottom samples, and seismic reflection profiles (where they existed). Surficial geology maps and reports for the ACAD region include: Timson (1976); Barnhardt et al. (1996a)[218]; and Barnhardt et al. (1996b)[219].

A compilation of data for the Gulf of Maine inner continental shelf includes a 1991 report on the seafloor geomorphology, surficial sediments, and stratigraphy in the vicinity of Blue Hill and Frenchman Bays[217] (Barnhardt and Kelley 1991). The study focuses on the nearshore out to 100 m. An EG&G model 260 Seafloor Mapper was used to collect 330 km of sidescan sonar records (see *ACAD—Bedrock geology and shallow stratigraphy*). Sidescan sonar data were used in conjunction with bottom sampling to ground-truth seismic reflection data and to interpret bottom sediment texture and composition. Tracklines are located in Somes Sound and in the near vicinity of the south and southeast borders of the park. The study also references a previous sidescan sonar survey in the Penobscot Bay region (Scanlon and Knebel 1989) and a bottom sediment mapping project in Somes Sound (Folger et al. 1972).

Sediment grain size and organic content

Sediment grain size and organic content data for ACAD consist of national and regional datasets such as EPA's NCA and NARS, CONMAP, usSEABED (nearly 20 points within park boundaries and hundreds within 1.6 km), the USGS Marine Aggregate Resources Project, and the East Coast Sediment Texture Database (5 points within park boundaries and ~100 points in Somes Sound just outside of park borders) (see *National and regional Datasets—Sediment grain size and organic content*). Very few sampling points from national and regional datasets fall directly within park boundaries, but hundreds of sampling points are located within a mile of the park's borders. In addition, the inventory identifies a number of localized grain size and organic content data records relevant to ACAD and a number of additional datasets were located during the writing of this report.

Bottom samples were collected as part of a Maine Geological Survey report and GIS compilation from seafloor surveys conducted in the western Gulf of Maine[216] (Kelley et al. 1998; see *ACAD—Bathymetry; Bedrock geology and shallow stratigraphy;* and *Acoustic seabed characterization*). Between 1984 and 1991, over 1,700 bottom sample stations were established in the northwestern Gulf of Maine as part of a variety of projects, yielding 1,303 bottom samples (reports relevant to ACAD are Barnhardt et al. 1996a, b). Varying by project, the samples were analyzed for grain size, organic carbon, nitrogen, carbonate content, and/or heavy mineral concentration. Textural and lithologic data for the Maine coastal area were clipped from the full Surficial Geology of the Maine Inner Continental Shelf map series[29, 216] (Poppe and Hastings 2003). The data draw from three previous sources (Kelley et al. 1998; Barnhardt et al. 1996a, b). Less than 10 sampling points are within or abut ACAD park boundaries and over 100 points are located within 8 km of the park.

From 1989 to 1990, 188 bottom samples were collected and analyzed for grain size, percent carbon and nitrogen, and bottom type weights as part of a report on the seafloor geomorphology, surficial sediments, and stratigraphy in the vicinity of Blue Hill and Frenchman Bays[217] (Barnhardt and Kelley 1991). One hundred thirty eight of these samples were concentrated in an area located between the southeast shore of Mount Desert Island and approximately 5 km offshore. None of the points are within park boundaries. Sampling data were used in conjunction with seismic reflection profile and sidescan sonar data to interpret bottom sediment texture and composition in the ACAD region (see also *ACAD—Acoustic seabed characterization* and *Bedrock geology and shallow stratigraphy*).

The Maine Geological Survey (ME GS) houses a black-and-white map series that illustrates the size and location of marine geologic environments along the Maine coast[224] (ME GS 2012). This series distinguishes the size and location of 55 marine supratidal, intertidal, and subtidal environments for the entire Maine coast from nearshore uplands to ~25-30 ft below the low-tide mark. The maps are currently unavailable online. Metadata were not readily available.

The Gulf of Maine Contaminated Sediment Database contains three sampling points located less than 8 km from the park's borders (Buchholtz ten Brink et al. 2002).

<u>Sediment contaminants</u>
Sediment contaminant data collected in the vicinity of ACAD are included in EPA's NCA and NARS (*see National and Regional Datasets—Sediment contaminants*).

<u>Water chemistry and water quality</u>
Water-chemistry and water-quality data for ACAD consist of national/regional datasets (see *National and regional Datasets*) and the following localized data sets.
The Maine Department of Marine Resources (ME DMR) conducts and coordinates shoreline sanitary surveys through the Shellfish Growing Area Classification Program[80]. Sanitary surveys include a shoreline survey, which identifies pollution sources that may impact water quality; water sampling to determine fecal coliform bacterial levels in marine water; and analysis of how weather conditions, tides, currents, and other factors may affect the distribution of pollutants in the area. There are many sampling stations along the ACAD shoreline (ME DMR 2012a). ME DMR also coordinates community-based volunteer monitoring of toxic phytoplankton species

along ME coast[81]. Volunteers collect water samples in the spring, summer, and fall using field microscopes to identify the phytoplankton species (ME DMR 2012b).

<u>Submerged habitats and biological communities</u>

Seagrass distribution

Statewide maps of submerged aquatic vegetation (SAV) along the Maine coast were produced by the Maine Department of Marine Resources (ME DMR) based on interpretation of 1:12,000-scale aerial photography collected from 1993 to 1997[104] (ME DMR 1999). The effort followed NOAA Coastal Service Center (CSC) Coastal Change Analysis Protocol (CCAP) and benthic data were classified according to the System for Classification of Habitats in Estuarine and Marine Environments (SCHEME). Polygons delineating eelgrass beds were digitized on basemap features from 1:24,000-scale USGS topographic maps and classified based on percent cover. Estimated minimum mapping unit is 150 sq. m. Horizontal accuracy meets national standards and vertical accuracy was not tested. Statewide eelgrass maps were prepared again based on aerial photography acquired from 2001 to 2005. Both the 1993 to 1997 and the 2001 to 2005 datasets are provided as shapefiles by the Maine Office of Geographic Information Systems[106] (ME GIS 2011). Eelgrass maps can be viewed online (ME DMR 2009).

Biological communities and species inventories

Benthic community and species data for ACAD have been produced for a variety of objectives, and include a range of geographic coverages, resolutions, and data formats. Examples include:

(1) GPS mapping of tidepools on Mount Desert Island from Anemone Cave to Otter Cove in 1999 (no citation; shapefile only);

(2) PDF maps of Water Resources and Riparian Habitats, High Value Plant and Animal Habitats, Undeveloped Habitat Blocks, Wetlands Characterization, and other supplemental habitat information for the state of Maine generated through the Beginning with Habitat program[107]. The maps integrate sources of habitat data throughout the state such as wetlands data from The National Wetlands Inventory (NWI); Atlantic Salmon spawning and rearing habitats mapped by the Atlantic Salmon Commission and the U.S. Fish and Wildlife Service (USFWS); records for rare, threatened, and endangered species tracked in NaturalServe (Natural Heritage Network) for Maine; areas defined and mapped by the Maine Department of Inland Fisheries and Wildlife (ME DIFW) as Significant Wildlife Habitat for rare and endangered species, Atlantic salmon, waterfowl, wading birds, and seabirds; and datasets related to mapping of valuable habitat for USFWS priority trust species. Notably, areas of ACAD make up a significant portion of the state's Focus Areas of Statewide Ecological Significance identified by the Department of Conservation (Maine Natural Areas Program) and the ME DIFW;

(3) A coast-wide, 1:24,000-scale shellfish habitat map created by the Maine Office of GIS, coded by shellfish type[108];

(4) A 1992 1:24,000-scale map of marine worm habitat throughout the state coded by worm type[109].

(5) A National Wetlands Inventory map for the Southwest Harbor, ME 7.5-minute quadrangle includes ACAD wetland areas[103].

Saugus Ironworks National Historic Site (SAIR)

As with CACO and BOHA, the Massachusetts Ocean Resources Information System (MORIS) is a relevant online source of geospatial data for SAIR (MA CZM 2011; see also *CACO* and

BOHA). Similarly, the Official Website of the Office of Geographic Information (MassGIS 2012) includes a database that houses all of Massachusetts digital GIS data. The database and datalayers include aerial photography, topographic reference maps, surficial geology basemaps, elevation data, digital elevation models, coastal and marine features data (beaches, tidelands, fish, shellfish, etc.), rare species, protected habitats, environmental monitoring, soils, hydrography, and other relevant data.

Bathymetry

Bathymetry data for SAIR include national, regional, and local datasets. The bathymetry datasets recorded in the inventory represent limited high-resolution coverage for this park. The following data descriptions summarize the datasets recorded in the inventory. Descriptions of relevant national and regional datasets are included in the *National and Regional Datasets* section.

Two Gulf of Maine coverages pertaining to SAIR are described in the *National and Regional Datasets—Bathymetry* section (Banner 2002; MassGIS 1999).

The NOAA Estuarine Bathymetry Project website[234] (NOAA 2007) features 3-arc-second (about 90-m) and 30-m resolution digital raster compilations for Massachusetts Bay (NOAA NOS 1998b). SAIR is located on a tidally-influenced, freshwater portion of a sub-estuary within Massachusetts Bay. Bathymetry for Massachusetts Bay was derived from 38 hydrographic surveys conducted by the NOAA National Ocean Service (NOS) from 1940 to 1970. Combined the surveys contain 297,628 soundings with an average separation of 57 m and covered depths from 3 m above to 71 m below mean low water. Massachusetts Bay has fifteen 7.5-minute digital elevation models (DEMS) and two 1-degree DEMs. Vertical accuracy of the bathymetric DEMs is estimated at 2% of depth (or 1 m for depths greater than 20 m and 0.20 m for depths shallower than 20 m).

In 2008, the Massachusetts Office of Coastal Zone Management (MA CZM) published a 30-m resolution mosaic of bathymetric datasets for all waters off the coast of Massachusetts, derived from "the most current and accurate sources"[236] (Figure 14; MA CZM 2008). The mosaic is relevant to SAIR (as well as CACO and BOHA) and is a compilation of bathymetric data varying in resolution from 2 m to 90 m. The data were developed to form a continuous bathymetric model for Massachusetts waters, covering the entire geographic extent with no known omissions (see also *CACO* and *BOHA—Bathymetry*).

The NOAA Coastal Services Center published coastal topographic and bathymetric lidar survey data for Maine, Massachusetts, and Rhode Island (NOAA CSC 2009; see also *National and Regional Datasets—Bathymetry*). The survey footprint and metadata (JALBTCX 2009) can be viewed on the NOAA Coastal Services Center Digital Coast Data Access Viewer (NOAA CSC 2012).

Hydrography

Wave height, direction, and periodicity

SAIR is considerably upriver from marine monitoring stations, so there are no buoys providing wave data immediately relevant to the park. The closest buoys are in Massachusetts Bay (Figure 26, Table 10). Buoy 44013 (LLNR 420, Boston), owned and operated by NOAA's National Data Buoy Center (NOAA NWS 2012b), is approximately 19 km east of Boston, MA. Buoy 44029

(A0102, Massachusetts Bay/Stellwagen), operated by the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS 2012), is located about 25 km east of Salem, MA, 35 km east-northeast of SAIR.

Tide range, phase, and currents

Tide data relevant to SAIR are collected at NOS Station 8443970 (NOAA NOS 2011) and USGS Station 01104715 (USGS 2012b), both in Boston, MA (Figure 29, Table 12).

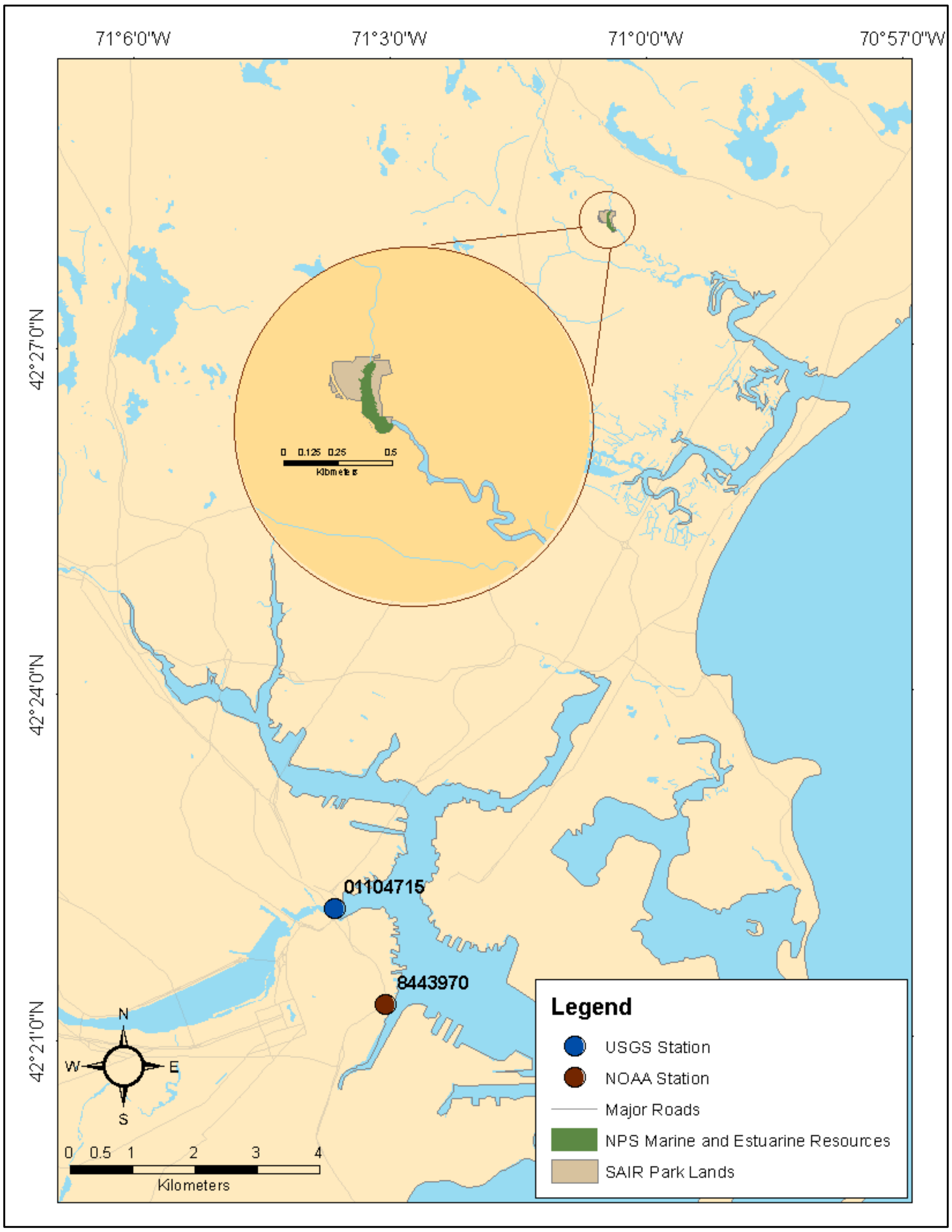

Figure 29. Hydrographic data collection stations in the vicinity of Saugus Iron Works National Historic Site (NERACOOS 2012, NOAA NOS 2011, NOAA NWS 2012b, USGS 2012b).

Table 12. Hydrographic data collected in the vicinity of Saugus Iron Works National Historic Site (NERACOOS 2012, NOAA NOS 2011, NOAA NWS 2012b, USGS 2012b).

SAIR	NOAA NOS Station	USGS Station
Station Codes	BHBM3 8443970	01104715
Wind Direction	-	-
Wind Speed	-	-
Wind Gust	-	-
Wave Height	-	-
Dominant Wave Period	-	-
Average Period	-	-
Mean Wave Direction	-	-
Atmospheric Pressure	+	-
Pressure Tendency	-	-
Air Temperature	+	-
Water Temperature	+	-
Dew Point / Relative Humidity	-	-
Water Level	+	+
Conductivity/Salinity	-	-

Hydrogeologic framework

Surface and groundwater pathways

Data on surface-water level, stream flow, and groundwater level are provided by the USGS National Water Information System (USGS 2012b, see *National and Regional Datasets—Hydrogeologic framework*).

Bedrock geology and shallow stratigraphy

The NPS Geologic Resources Inventory Scoping Report for SAIR provides a detailed evaluation of sources of bedrock and surficial geologic-data available and the actions necessary to use these data sources to meet mapping needs (Thornberry-Ehrlich 2008b*; see National and regional Datasets—Hydrogeologic framework*).

Surficial geology

Acoustic seabed characterization

No acoustic seabed characterization projects were recorded in the inventory for this park.

Sediment grain size and organic content

No sediment grain size or organic content sampling sites from national and regional datasets overlap with SAIR park boundaries.

Sediment contaminants

Sediment contaminant data collected in the vicinity of SAIR are included in EPA's NCA and NARS (see National and Regional Datasets—Sediment contaminants), as well as the following localized data set.

The Contaminated Sediments Database for the Gulf of Maine provides a synthesis of existing sediment data to aid analyses of environmental status, contaminant transport paths, and the fate of contaminants[43] (Buchholtz ten Brink et al. 2002). This database is the product of collaboration between principal investigators from USGS, Woods Hole Oceanographic Institution, the University of New Hampshire, Bigelow Laboratory for Ocean Sciences, the University of Massachusetts, and participants from the U.S. Army Corps of Engineers, EPA, NOAA, the Massachusetts Water Resources Authority, and other federal and state agencies. A subset of the database, released in 2002, is intended to aid interpretations of surficial sediment distribution off of the northeastern U.S. The datalayer contains grain size data from 852 points in the coastal waters of Massachusetts, Maine, and New Hampshire. Similarly, the Texture Table in the Gulf of Maine Database contains grain size information from over 4000 samples collected throughout the northeastern U.S. (Buchholtz ten Brink et al. 2002).

Water chemistry and water quality

Water-chemistry and water-quality data for SAIR consist of national/regional datasets (see *National and regional Datasets—Water chemistry and water quality*).

Submerged habitats and biological communities

Biological communities and species inventories

In the fall of 2002, MassDEP launched the Wetlands Change Project, an evaluation of wetland protection efforts in the state over the previous decade via remote sensing and GIS-based data analysis[133] (MassGIS 2011b). This project utilized state wetlands maps produced Mass DEP-WCP over 11 years through interpretation of aerial photography. The project used the 1:12000 DEP Wetlands datalayer, covering 70% of the state by 2002, to develop a digital database of wetland alterations made from 1990 to 2001. Later aerial imagery was superimposed on base wetland maps to assess changes over time. The datalayer currently comprises three polygon feature types, wetlands change from 2001/2003 imagery, wetlands change from 2005 imagery, and wetlands change from 2008/2009 imagery. The attribute codes in the polygon layer describe different types of wetland environments and different types of reasons for the wetlands change.

The Natural Heritage and Endangered Species Program (NHESP) database includes the Priority Habitats of Rare Species datalayer, with polygons showing the geographic extent of habitats for state-listed rare species[137] (MA NHESP 2008). The datalayer is based on observations of rare species documented over a 25 year period concluding in 2006. The habitat polygons were heads-up digitized in ArcView at a 1:25,000 scale and referenced to MassGIS's 2001 Color Orthophotos. Priority Habitats were digitized by NHESP scientists from documented observations of rare species and are based on such factors as species movements and habitat requirements.

Sagamore Hill National Historic Site (SAHI)

Bathymetry

Descriptions of relevant national and regional datasets are included in the *National and Regional Datasets* section.

SAHI is encompassed within 3-arc-second (about 90-m) and 30-m resolution digital raster compilations of NOAA National Ocean Service (NOS) hydrographic soundings for Long Island Sound (NOAA NOS 1998c). Available on the NOS Estuarine Bathymetry Project website[234] (NOAA 2007), the bathymetric data are derived from 55 NOS hydrographic surveys conducted from 1931 to 1939 containing 562,596 soundings with an average separation of 77 m. Depths of soundings ranged from 2.1 m above and 113.4 m below mean low water. Long Island Sound has fifty-one 7.5-minute DEMs and five 1-degree DEMs.

Hydrography

Wave height, direction, and periodicity

There are no regional monitoring buoys providing real-time data on wave height in the vicinity of SAHI, which is located on the shores of Cold Spring Harbor in southwestern Long Island Sound. However, wind data are provided by University of Connecticut buoy 44022, moored 20 km west of the park off Sands Pointe, New York (NOAA NWS 2012b), and NOAA NOS station 8516945 (KPTN6), located 24 km west-southwest of the park on Kings Point, New York (Figure 30, Table 13, NOAA NOS 2011).

Tide range, phase, and currents

Tide range and phase data relevant to SAHI come from three monitoring stations: one is operated by NOAA's National Ocean Service and two are operated by USGS (Figure 30, Table 13). NOAA station 8516945 (KPTN6) is located 24 km west-southwest of the park on the west side of Kings Point, New York (NOAA NOS 2011); USGS station 01302250 is 18 km west of the park at the Beach Rd. Bridge, Sands Point, New York; and USGS Station 01302845 is 9 km west-northwest of the park at the Sheep Lane Bridge, Lattingtown, New York (USGS 2012b).

Hydrogeologic framework

Surface and groundwater pathways

In addition to localized sources below, data on surface-water level, stream flow, and groundwater level are provided by the USGS National Water Information System (USGS 2012b, see *National and Regional Datasets—Hydrogeologic framework*).

Relevant to SAHI (as well as GATE and FIIS), a 4-page fact sheet produced by Schubert et al. (1997) evaluates ground-water resources in Long Island and describes techniques for simulating ground-water flow[205]. The fact sheet provides a description of Long Island's aquifers, stresses on the area's ground-water flow system, and patterns and rates of groundwater movements. In addition, the document presents information on Long Island's hydrogeologic framework, hydrologic boundaries, and hydraulic stresses, including the results of a particle tracking procedure used to define flow paths and delineate recharge areas. A GIS database was developed to incorporate model input, output, and particle tracking data.

An earlier hydrologic investigations atlas (Smolensky et al. 1989) presents seven maps and vertical sections showing the hydrogeologic framework of deposits that form Long Island's ground-water system[204]. These include 1:250,000 scale maps showing the configuration of the bedrock surface, the altitude of Cretaceous deposits and bedrock beneath the upper glacial aquifer, and the altitude of the upper surface of the Raritan Confining Unit, Gardiner's clay, and the Lloyd, Monmouth, Jameco, and Magothy Aquifers. Hydrogeologic data from more than 3,100 wells were used to interpret the altitude of the upper surface of each hydrogeologic unit. Seismic survey data from previous studies were used to correlate onshore and offshore data and to project the extent of hydrogeologic units offshore. The atlas provides a description of the erosional and depositional history in Long Island derived from a theoretical sedimentation model and consequent interpretations of the type, location, and thickness of sediments.

Buxton and Smolensky (1999) simulated the effects of development on groundwater flow in Long Island providing surface and groundwater predictions applicable to SAHI (as well as FIIS and GATE (see *National and Regional Datasets—Hydrogeologic framework*).

Bedrock geology and shallow stratigraphy
The NPS Geologic Resources Inventory (GRI) Scoping Report for SAHI provides a detailed evaluation of sources of geologic data relevant to the park (Thornberry-Ehrlich 2011c; *see National and regional Datasets—Hydrogeologic framework*). Participants identified existing hydrogeology maps that could be digitized to meet park needs and the GRI Program made plans to fund acquisition of complementary surficial mapping data. Shoreline erosion is a very real threat to the park and participants noted the potential to study dimensional changes in shoreline geomorphology using aerial photographs through time.

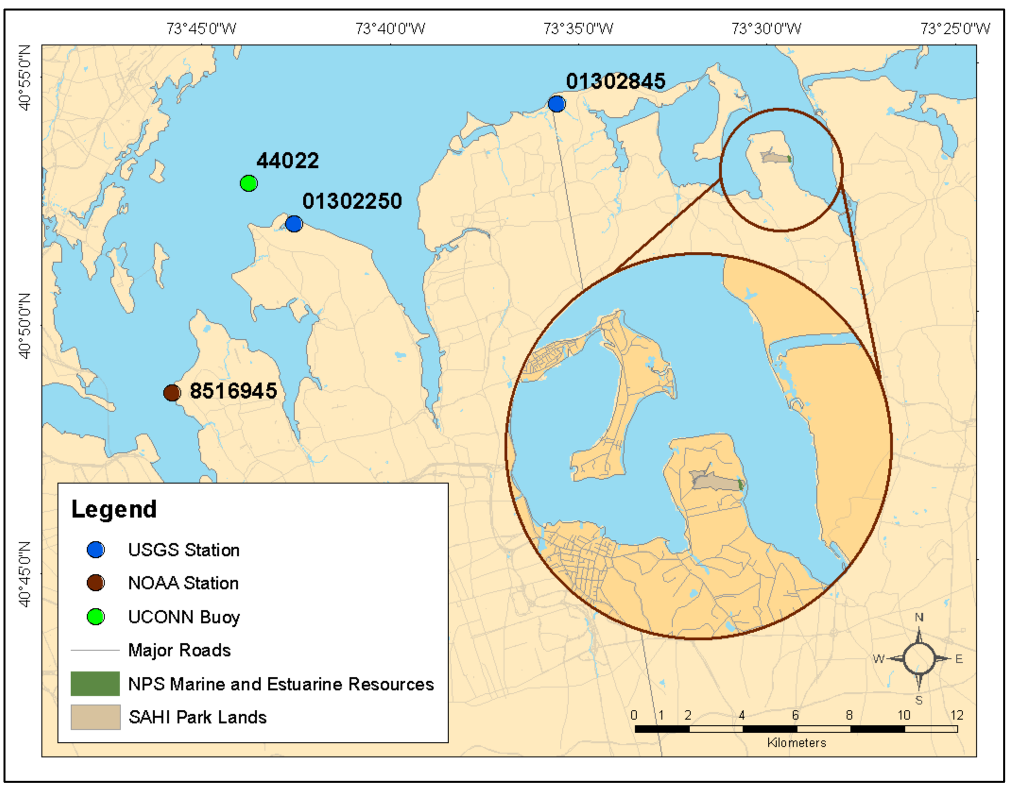

Figure 30. Hydrographic monitoring stations in the vicinity of Sagamore Hill National Historic Site (NOAA NOS 2011, NOAA NWS 2012b, USGS 2012b).

Table 13. Hydrographic data collected in the vicinity of Sagamore Hill National Historic Site (NOAA NOS 2011, NOAA NWS 2012b, USGS 2012b).

SAHI	NOAA NOS Station	University of CT Moored Buoy	USGS Stations	
Station Codes	KPTN6 8516945	44022	01302845	01302250
Wind Direction	+	+	-	-
Wind Speed	+	+	-	-
Wind Gust	+	+	-	-
Wave Height	-	-	-	-
Dominant Wave Period	-	-	-	-
Average Period	-	-	-	-
Mean Wave Direction	-	-	-	-
Atmospheric Pressure	+	+	-	-
Pressure Tendency	-	-	-	-
Air Temperature	+	+	-	-
Water Temperature	+	+	+	+
Dew Point / Relative Humidity	-	+	-	-
Water Level	+	-	+	+
Conductivity/Salinity	-	+	+	+

Surficial geology

Sediment grain size and organic content

No sediment grain size or organic content sampling sites from national and regional datasets overlap with SAHI park boundaries. Three sampling points within the usSEABED database are within one mile of the park border.

Sediment contaminants

Sediment contaminant data collected in the vicinity of SAHI are included in EPA's NCA and NARS (*see National and Regional Datasets—Sediment contaminants*).

Water chemistry and water quality

Water-chemistry and water-quality data for SAHI consist of national/regional datasets (see *National and regional Datasets*) and the following localized data set.

Friends of the Bay monitors water quality in the Oyster Bay/Cold Spring Harbor Estuary, including dissolved oxygen, nitrogen, coliform bacteria, water clarity (Secchi depth)[100]. Monitoring occurs weekly from April through October. Annual reports for the years 1999 to 2006 are available from (Friends of the Bay 2010), along with a map of their sampling stations. Samples are collected in Cold Spring Harbor and Oyster Bay Harbor, which surround the Cove Neck peninsula where SAHI is located.

Colonial National Historical Park (COLO)

Bathymetry

The following data descriptions summarize the bathymetric datasets recorded in the inventory for COLO. Descriptions of relevant national and regional datasets are included in the *National and Regional Datasets* section.

The NOAA Estuarine Bathymetry Project[234] (NOAA 2007) derived 3-arc-second (about 90-m) and 30-m resolution digital raster compilations of NOAA National Ocean Service (NOS) hydrographic soundings for select U.S. estuaries. COLO is encompassed within a compilation map for the Chesapeake Bay (NOAA NOS 1998d). Chesapeake Bay bathymetry was derived from 297 NOS hydrographic surveys dating from 1859 to 199. A total of 3,178,509 soundings were collected at depths ranging from 3.7 m above to 50.4 m below mean low water. Two hundred-eighteen 7.5-minute digitial elevation models (DEMs) and 10 1-degree DEMs are available for the Cheasapeake Bay.

One-meter low water bathymetric contours are available for the mainstem Chesapeake Bay, containing data that are within 5 km of COLO park boundaries[3] (Chesapeake Bay Program 1997). Contours were generated by interpolating hydrographic survey data (about 3.5 million soundings) from the NOAA Hydrographic Survey Data CD-ROM.

In April 2004, the Virginia Institute of Marine Science (VIMS) conducted swath bathymetry and sidescan sonar surveys at Catlett and Goodwin Islands on the York River using an interferometric (Swathplus 234 kHz) swath system[38] (NOAA CSC and VIMS 2005a, b; see also *COLO—Acoustic seabed characterization*). The raster file of bathymetry data for Catlett Island provides a swath (about 2 km by less than 1 km) of high-resolution bathymetry located 2 km from COLO's York River boundary. The bathymetry data for Goodwin Island covers an equivalent size swath located 6.5 km from COLO's York River boundary.

Hydrography

A data layer containing vector lines and polygons of Virginia coastal hydrography has been created as part of the development of an Environmental Sensitivity Index (ESI) for Virginia (NOAA 2012; see *National and Regional Datasets* and *COLO—Submerged Habitats and Biological Communities*). The HYDRO data layer contains data organized by geographic, socioeconomic, and water features spanning from 1998 to 2004. This dataset is part of a larger ESI dataset characterizing the sensitivity of Virginia's marine and coastal resources to spilled oil. Data sources used in the compilation of dataset are described within the metadata.

Wave height, direction, and periodicity

Data on wave height relevant to COLO are collected by one moored buoy, 44041, owned and maintained by the Chesapeake Bay Interpretive Buoy System (NOAA NWS 2012b). This buoy is located on the west side of Jamestown Island, VA, just outside of the park boundaries (Figure 31, Table 14). In addition, wind data are provided by NOAA NOS stations 8637689 (YKTV2) on the shores of the York River at Yorktown, VA and 8637611 (YKRV2), at the mouth of the York River (Figure 31, Table 14, NOAA NOS 2011).

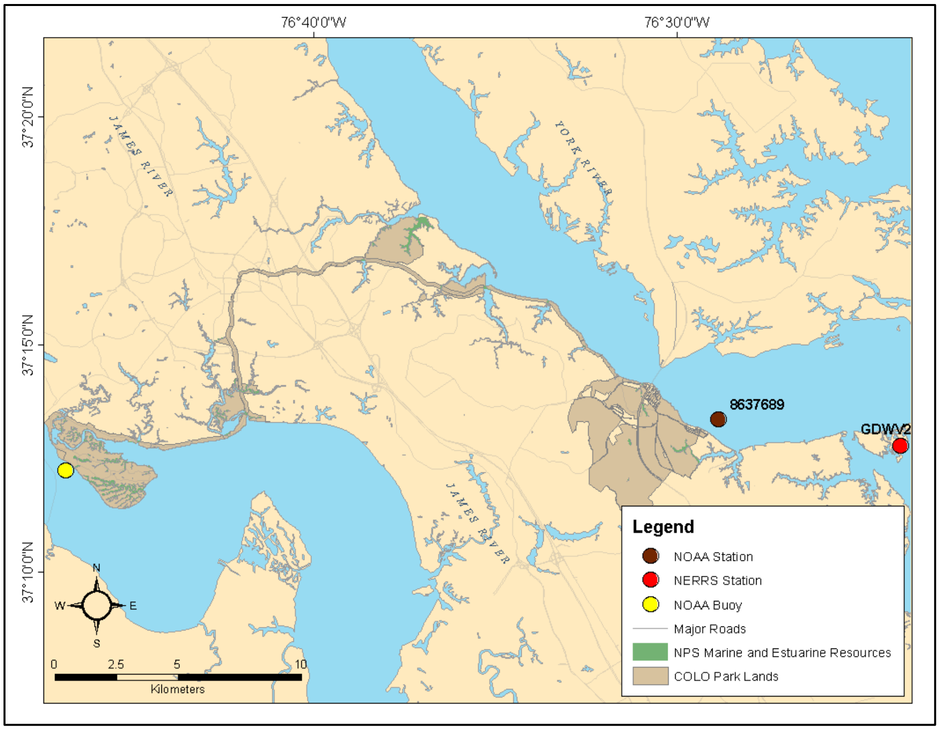

Figure 31. Hydrographic monitoring stations in the vicinity of Colonial National Historic Park (NOAA NOS 2011, NOAA NWS 2012b).

Table 14. Hydrographic data collected in the vicinity of Colonial National Historic Park (NOAA NOS 2011, NOAA NWS 2012b).

COLO	Ches. Bay Interpretive Buoy	NERRS Station	NOAA NOS Stations	
Station Name			**YKTV2**	**YKRV2**
Station Code	**44041**	**GDWV2**	**8637689**	**8637611**
Wind Direction	+	-	+	+
Wind Speed	+	-	+	+
Wind Gust	+	-	+	+
Wave Height	+	-	-	-
Dominant Wave Period	-	-	-	-
Average Period	-	-	-	-
Mean Wave Direction	-	-	-	-
Atmospheric Pressure	+	-	+	+
Pressure Tendency	-	-	-	-
Air Temperature	-	-	+	+
Water Temperature	+	+	+	-
Dew Point / Relative Humidity	-	-	-	-
Water Level	-	+	+	-
Conductivity/Salinity	+	+	-	-

Tide range, phase, and currents
Data on tide range and phase in the vicinity of COLO are collected at NOAA NOS Station 8637689 (YKTV2, Yorktown, VA, NOAA NOS 2011), 3 km southeast of Yorktown, VA, and station GDWV2, owned and maintained by the National Estuarine Research Reserve System (NERRS), located off of Goodwin Island at the mouth of the York River (Figure 31, Table 14, NOAA NWS 2012b). These monitoring stations are located in the York River and thus do not provide direct data for the Historic Jamestown area of the park, where the predominant estuarine resources are located.

<u>Hydrogeologic framework</u>
Surface and groundwater pathways
In addition to localized sources below, data on surface-water level, stream flow, and groundwater level are provided by the USGS National Water Information System (USGS 2012b, see *National and Regional Datasets—Hydrogeologic framework*).

Heywood and Pope (2009) developed a groundwater model that simulates the evolution of water levels in the aquifers and confining units of the Virginia Coastal Plain since 1890. The primary function of the model is to assess the status and predict changes in the regional groundwater levels in the confined aquifers beneath the Coastal Plain.

Bedrock geology and shallow stratigraphy
The NPS Geologic Resources Inventory (GRI) Scoping Report for COLO lists the available sources of bedrock and surficial geologic data relevant to the park (Thornberry-Ehrlich 2005b; *see National and regional Datasets—Hydrogeologic framework*). Meeting participants also identified other related maps that exist for the region, including coverage of mineral and mineral potential, structural geology, topography, and aeromagnetic gravity.

<u>Surficial geology</u>
Acoustic seabed characterization
In April 2004, the VIMS conducted swath bathymetry and side scan sonar surveys at Catlett and Goodwin Islands on the York River using an interferometric Swathplus 234-kHz swath system[38] (NOAA CSC and VIMS 2005a, b; see also *COLO—Bathymetry*). Sidescan-sonar imagery covers about 2 km by less than 1 km swaths near Catlett and Goodwin Islands, within 2 km and 6.5 km of COLO's York River boundary, respectively. Sediment grab sample and sediment profile image (SPI) data were also collected in 2002, 2003, and 2004 through a benthic mapping project of VIMS and the NOAA Coastal Services Center (CSC) and used to interpret the acoustic data. The acoustic, grab, and SPI information were used in conjunction to characterize benthic habitats and to examine relationships between animal communities and sediment characteristics.

Older sidescan sonar data for the York River Estuary was collected by VIMS as part of an analysis of side-scan sonar as a tool for mapping sediment type variations (Hobbs 1985).

Sediment grain size and organic content
Sediment grain size and organic content data within the vicinity of COLO consist of national and regional datasets such as EPA's NCA and NARS, CONMAP, usSEABED (0 points within park boundaries, about 30 points within 3 km), and the USGS Marine Aggregate Resources Project (see *National and regional Datasets*), as well as the following localized datasets.

Sediment grab sample and sediment profile image (SPI) data were collected at Catlett and Goodwin Islands on the York River, VA (several km outside of COLO boundaries) in 2002, 2003, and 2004. The data were used to groundtruth acoustic data collected as part of a benthic mapping project of VIMS and the NOAA Coastal Services Center (CSC)[38] (NOAA CSC and VIMS 2005c, d; *see also COLO—Bathymetry* and *Acoustic seabed characterization*). Sediment grab samples collected at 56 stations in 2002, 24 in 2003, and 12 in 2004 were analyzed for grain size and organic content. The acoustic, grab, and SPI information were used in conjunction to characterize benthic habitats by the islands and to examine relationships between animal communities and sediment characteristics *(See also COLO—Submerged habitats and biological communities).* The grab sample sites are located several km outside of COLO park boundaries.

The Virginia Department of Environmental Quality (DEQ) released a statewide integrated water quality assessment in 2008, containing sediment grain size information pertinent to COLO[215] (VA DEQ 2008). The report includes monitoring results from Virginia's estuarine probabilistic monitoring module that was initiated in 2000 with a grant from EPA's NCA Program. Through this module, sites were sampled from 2000 to 2004 from Virginia's portion of the Chesapeake Bay mainstem and the tidal portions of its major tributaries. The samples were analyzed for sediment particle size, as well as a host of water quality and contaminant parameters (see also *COLO—Water chemistry and water quality* and *Grain size and organic content*). Note that a final 2010 report of this assessment, GIS data, and printable maps are available for download online (VA DEQ 2011). Fewer than 20 of the monitoring stations in any year were within COLO park boundaries.

The Maryland Geological Survey and VIMS produced a baseline inventory of Chesapeake Bay bottom sediments as part of a cooperative effort between the states of Maryland and Virginia, funded by the Environmental Protection Agency. The Maryland Geological Survey and VIMS were responsible for sampling and analyzing sediments for their respective states and used identical methodology. VIMS collected and analyzed over 2,000 grab samples in the Virginia portion of the Bay for grain size (Byrne et al. 1980). Nine hundred of these samples were also analyzed for carbon, organic carbon, and sulphur content. Taken together, these datasets represent sediment data collected from 1976 to 1984 throughout the Chesapeake Bay mainstem.

A brief Internet search conducted post-inventory suggests that additional reports may be available and relevant to surficial sediment characterization in the vicinity of COLO (e.g., Friedrichs 2009; Dellapenna et al. 2001).

<u>Sediment contaminants</u>

Sediment contaminant data collected in the vicinity of COLO are included in EPA's NCA and NARS (*see National and Regional Datasets—Sediment contaminants*), as well as the following localized data set.

The Virginia Department of Environmental Quality (VA DEQ) released a statewide integrated water quality assessment in 2008, containing water quality and sediment contaminant data pertinent to COLO[215] (VA DEQ 2008). Through this program, about 35 sites were sampled from 2000 to 2004 from Virginia's portion of the Chesapeake Bay mainstem and the tidal portions of its major tributaries. Sediment parameters included sediment particle size, total organic carbon (TOC), toxicity, metals, organic contaminants, and bacterial contaminants (see also *COLO—*

Water chemistry and water quality and *Sediment grain size and organic content*). A final 2010 report of this assessment, GIS data, and printable maps are available for download online (VA DEQ 2011).

Water chemistry and water quality

Water-chemistry and water-quality data for COLO consist of national/regional datasets (see *National and regional Datasets*), as well as the following localized datasets.

The Virginia Department of Environmental Quality (DEQ) released a statewide integrated water quality assessment in 2008, containing data pertinent to COLO[214] (VA DEQ 2008). The report is a summary of the water quality conditions in Virginia from 2001 to 2006 to satisfy requirements of the U.S. Clean Water Act sections 305(b) and 303(d) and the Virginia Water Quality Monitoring, Information, and Restoration Act. DEQ conducted water-quality monitoring from 2003-2008 at 4,573 stations, including measurements for temperature, pH, dissolved oxygen, specific conductivity, salinity, nutrients, bacteria, metals, pesticides, herbicides, and toxic organic compounds. In total, 687 different parameters were sampled for a total of 1,469,474 data points. The report also includes monitoring results from Virginia's estuarine probabilistic monitoring module that was initiated in 2000. Through this module, about 35 sites were sampled from 2000 to 2004 from Virginia's portion of the Chesapeake Bay mainstem and the tidal portions of its major tributaries. Water column parameters measured included temperature, pH, DO, salinity, PAR profiles, chlorophyll, nutrients, suspended solids, and bacterial and chemical contaminants (see also *COLO—Sediment contaminants*). Lastly the report includes results of beach and citizen water quality monitoring programs.

Three papers and shapefiles include water-quality data collected within COLO:

(1) Baseline water quality information for the Back River System, Jamestown Island in COLO digitized by USFSW in 1991[148] (USFWS 1991).
(2) Baseline water quality information for the Cheatham Annex Naval Supply Center in Williamsburg, VA digitized by USFWS in 1994[149] (USFWS 1994); and
(3) Baseline water quality information for Swann's Point, Kingsmill Neck, and Wormley Pond digitized by USFWS in 1998[150] (USFWS 1998). The data includes pH, temperature, and salinity measurements.

Submerged habitats and biological communities

Seagrass distribution

The Virginia Institute of Marine Science has produced periodic maps of submerged aquatic vegetation (SAV) in Chesapeake Bay and the Maryland coastal bays since 1986[151, 152]. Mapping data are compiled in reports representing one year of coverage. Annual coverages and reports have been produced since 1997, and individual coverages exist also for 1986, 1989, 1991, 1992, 1994, and 1995[118]. The reports (e.g., Orth et al. 1987, 1998) describe the boundaries and density classes of mapped SAV each year. Data from 1974 to 1990 are compiled into a single coverage. SAV was mapped through interpretation of 1:24,000-scale aerial photographs.

Biological communities and species inventories

The Virginia Department of Environmental Quality (DEQ) released a statewide integrated water quality assessment in 2008, containing identification information for macroinvertebrate benthic infauna species in COLO[215] (VA DEQ 2008) (see also *COLO—Water chemistry and water quality, Sediment Contaminants,* and *Sediment grain size and organic content*). Note that a final 2010 report of this assessment, GIS data, and printable maps are available for download online (VA DEQ 2011).

Sediment profile image (SPI) data were collected at Catlett and Goodwin Islands on the York River, VA (several km outside of COLO boundaries) in 2002, 2003, and 2004 through a benthic mapping project conducted by VIMS and NOAA CSC[143] (NOAA CSC and VIMS 2005c; see also *COLO—Bathymetry*, *Acoustic seabed characterization*, and *Sediment* grain size *and organic content*). Sediment profile images were collected at 200 stations in 2002 and at a subset of 79 stations in 2004. SPI information was used in conjunction with acoustic, grab sample, and coring data to characterize benthic habitats by the islands and to examine relationships between animal communities and sediment characteristics. SPI data was evaluated according to the Bencore image analysis system for measuring SPI camera slides (Viles and Diaz 1991). Identification and enumeration of infauna, biomass, and benthic community parameters were also measured from benthic grab samples. Data for commercially important infaunal species and species of interest were collected at 92 stations in 2002, 24 statios in 2003, and 12 stations in 2004[144] (NOAA CSC and VIMS 2005d). The closest of all of the SPI and grab sample data points is approximately 1.5 km from COLO park boundaries.

An Environmental Sensitivity Index atlas was developed for Virginia, which contains a digital geodatabase on biological resources sensitive to oil spills[140] (see *National and Regional Datasets*).

Four papers and shapefiles describe fish resources within COLO:

(1) A point coverage data layer by USFWS using 1987 fish species composition data collected in selected COLO streams[147] (USFWS 1987; COLO 2005).
(2) A fishery inventory and baseline water quality information for the Back River System, Jamestown Island in COLO digitized by USFSW in 1991[148] (USFWS 1991).
(3) A fish inventory and baseline water quality information for the Cheatham Annex Naval Supply Center in Williamsburg, VA digitized by USFWS in 1994[149] (USFWS 1994); and
(4) A qualitative inventory of fisheries resources and baseline water quality information for the tidal environment of COLO digitized by USFWS in 1998[150] (USFWS 1998). This inventory includes data on abundance, size, range, and capture season for individual species.

George Washington Birthplace National Monument (GEWA)

Bathymetry

The following data descriptions summarize the bathymetric datasets recorded in the inventory for GEWA. Descriptions of relevant national and regional datasets are included in the *National and Regional Datasets* section.

The NOAA Estuarine Bathymetry Project[234] (NOAA 2007) derived 3-arc-second (about 90 m) and 30-m resolution digital raster compilations of NOAA National Ocean Service (NOS) hydrographic soundings for select U.S. estuaries. GEWA is encompassed within a compilation map for the Chesapeake Bay (NOAA NOS 1998d). Chesapeake Bay bathymetry was derived from 297 NOS hydrographic surveys dating from 1859 to 199. A total of 3,178,509 soundings were collected at depths ranging from 3.7 m above to 50.4 m below mean low water. Two hundred-eighteen 7.5-minute digitial elevation models (DEMs) and 10 1-degree DEMs are available for the Cheasapeake Bay.

One-meter low water bathymetric contours are available for the mainstem Chesapeake Bay, but the dataset boundaries are more than 50 km from GEWA[3] (Chesapeake Bay Program 1997). Contours were generated by interpolating hydrographic survey data (about 3.5 million soundings) from the NOAA Hydrographic Survey Data CD-ROM.

Hydrography

Wave height, direction, and periodicity

GEWA is located in the northern neck of Virginia, bordering the northern edge of the mouth of Popes Creek, a tributary of the Potomac River. There is no real-time monitoring of wave parameters in the immediate vicinity, but there are two sources of wind data on the Potomac River near GEWA (Figure 32, Table 15): Buoy 44067, owned and operated by Intellicheck Mobilisa, is at the Rt. 301 bridge approximately 21 km up the Potomac River from the park, and NOS Station 8578240 (PPTM2) is approximately 34 km down river from the park, at Piney Point, MD (NOAA NWS 2012b).

Tide range, phase, and currents

Tidal current data in the Potomac River is collected by the NOAA Potomac River Mid-channel buoy cb0901, about 34 km downriver from the park (Figure 32, Table 15, NOAA NOS 2011).

Hydrogeologic framework

Vector digital data showing the location of a seawall along the Potomac River at GEWA as it existed in 2003 was created as a reference for shoreline erosion[75] (Bush date unknown).

Surface and groundwater pathways

In addition to localized sources below, data on surface-water level, stream flow, and groundwater level are provided by the USGS National Water Information System (USGS 2012b, see *National and Regional Datasets—Hydrogeologic framework*).

The NPS Geologic Resources Inventory (GRI) Scoping Report for GEWA underscores the need to understand the hydrogeologic system and recommends use of existing wells to study groundwater flow (Thornberry-Ehrlich 2009*;* see *National and regional Datasets—Hydrogeologic framework*). Heywood and Pope (2009) developed a groundwater model that simulates the evolution of water levels in the aquifers and confining units of the Virginia Coastal Plain since 1890. The primary function of the model is to assess the status and predict changes in the regional groundwater levels in the confined aquifers beneath the Coastal Plain. Of particular importance to GEWA, most water-level observations forming the basis of the model were from the Potomac aquifer system, allowing for a complex spatial distribution of simulated hydraulic conductivity within the Potomac aquifer.

Bedrock geology and shallow stratigraphy

The NPS GRI Scoping Report for GEWA lists existing sources of geologic mapping for the primary quadrangles of interest to the park (Thornberry-Ehrlich 2009; see *National and regional*

Datasets—Hydrogeologic framework). Scoping meeting participants identified many maps relevant to GEWA that are produced by federal and state agencies, including coverage of geology, shoreline change, aeromagnetic-gravity, minerals and mineral potential, hydrogeology, and stratigraphy. The landscape at GEWA is strongly influenced by dynamic erosion and sedimentation processes along its Potomac River and Popes Creek shorelines, and the GRI Report summarizes detailed shoreline change studies undertaken by scientists at the Virginia Institute of Marine Science.

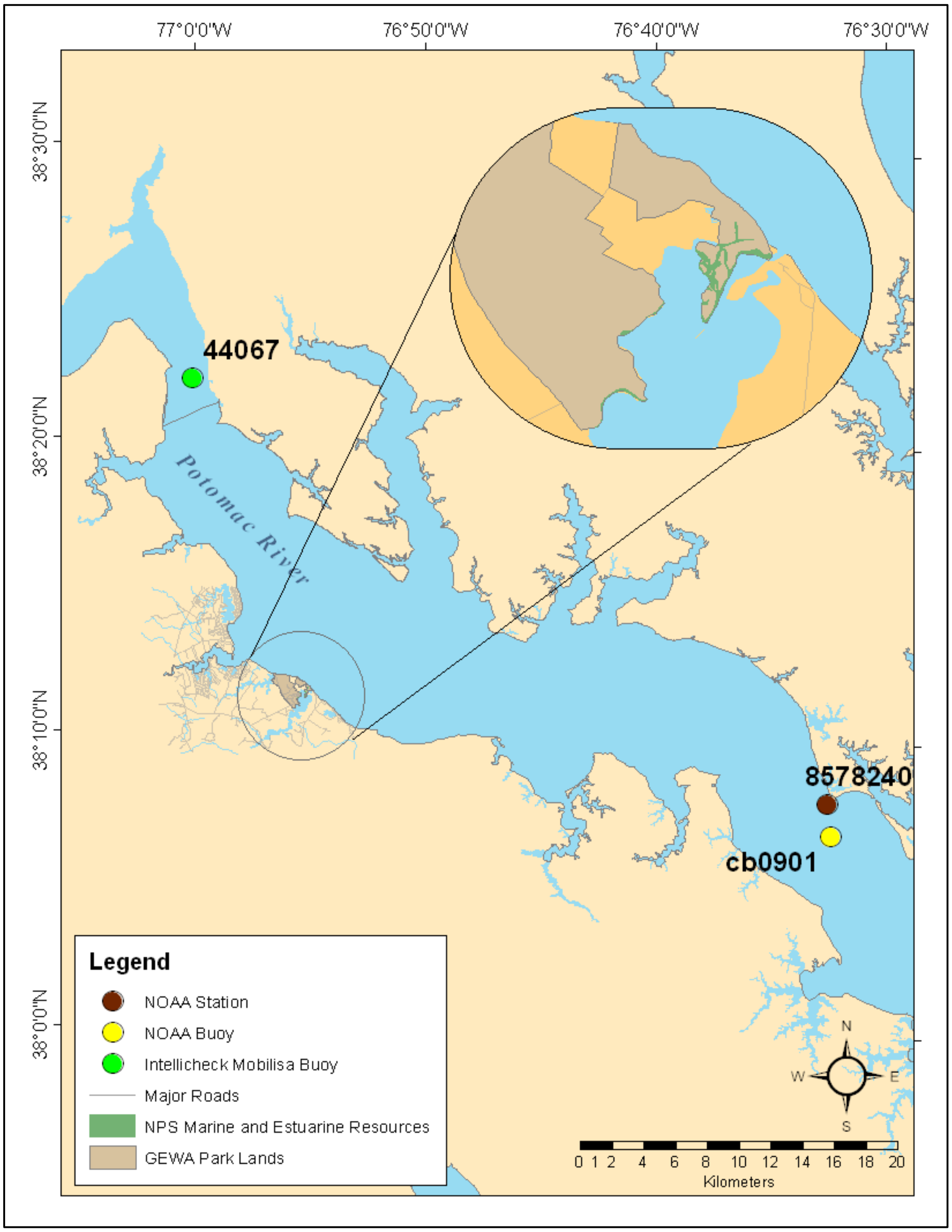

Figure 32. Hydrographic monitoring stations in the vicinity of George Washington Birthplace National Monument (NOAA NOS 2011, NOAA NWS 2012b).

Table 15. Hydrographic data collected in the vicinity of George Washington Birthplace National Monument (NOAA NOS 2011, NOAA NWS 2012b).

GEWA	Intellicheck Mobilisa Buoy	NOAA NOS Station	NOAA PORTS Buoy
Station Name		**PPTM2**	
Station Code	**44067**	**8578240**	**cb0901**
Wind Direction	+	+	-
Wind Speed	+	+	-
Wind Gust	-	+	-
Wave Height	-	-	-
Dominant Wave Period	-	-	-
Average Period	-	-	-
Mean Wave Direction	-	-	-
Atmospheric Pressure	+	-	-
Pressure Tendency	+	-	-
Air Temperature	+	-	-
Water Temperature	-	-	-
Dew Point / Relative Humidity	-	-	-
Water Level	-	-	-
Conductivity/Salinity	-	-	-
Currents	-	-	+

Surficial geology

Sediment grain size and organic content

No sediment grain size or organic content sampling sites from national and regional datasets overlap with GEWA park boundaries. Two sediment grain size and organic content sampling sites within the usSEABED database are within 8 km of the park's borders.

The Maryland Geological Survey and VIMS produced a baseline inventory of Chesapeake Bay bottom sediments as part of a cooperative effort between the states of Maryland and Virginia, funded by the Environmental Protection Agency. The Maryland Geological Survey and VIMS sampled and analyzed sediments for their respective states and used identical methodology. Between 1976 and 1984, the Maryland Geological Survey collected one sediment sample every square km within the Maryland section of the Bay for a total of 4,255 surface sediment samples[42] (MGS 2005). The samples were analyzed for grain size, as well as water, carbon, and sulfur content, and classified using the Shepard's sediment classification system. A sediment distribution map was developed showing the grain size composition of sediments along the bay seafloor within the Maryland portion of the Bay. The map and data are available as a GIS data set, an Adobe Acrobat PDF file, an online raster map, and an interactive map. The Virginia Institute of Marine Science collected and analyzed over 2,000 grab samples in the Virginia portion of the Bay for grain size (Byrne et al. 1980). Nine hundred of these samples were also analyzed for carbon, organic carbon, and sulphur content. Taken together, these datasets represent sediment data collected from 1976 to 1984 throughout the Chesapeake Bay mainstem. The data extent for these two studies stops 18 km from the GEWA boundary.

<u>Sediment contaminants</u>

Sediment contaminant data collected in the vicinity of GEWA are included in EPA's NCA and NARS (*see National and Regional Datasets—Sediment contaminants*), as well as the following localized data set.

The Virginia Department of Environmental Quality (DEQ) released a statewide integrated water quality assessment in 2008, containing water quality and sediment contaminant data pertinent to GEWA[215] (VA DEQ 2008). The report includes monitoring results from Virginia's estuarine probabilistic monitoring module that was initiated in 2000 with a grant from EPA's NCA Program. Through this module, ~35 sites were sampled from 2000-2004 from Virginia's portion of the Chesapeake Bay mainstem and the tidal portions of its major tributaries. Sediment parameters included sediment particle size, total organic carbon (TOC), toxicity, metals, organic contaminants, and bacterial contaminants (see also *GEWA—Water chemistry and water quality*). Note that a final 2010 report of this assessment, GIS data, and printable maps are available for download online (VA DEQ 2011).

<u>Water chemistry and water quality</u>

Water-chemistry and water-quality data for GEWA consist of national/regional datasets (see *National and regional Datasets*), as well as the following localized datasets.

The Virginia Department of Environmental Quality (DEQ) released a statewide integrated water quality assessment in 2008, containing data pertinent to GEWA[214] (VA DEQ 2008). The report is a summary of the water quality conditions in Virginia from 2001 to 2006 to satisfy requirements of the U.S. Clean Water Act sections 305(b) and 303(d) and the Virginia Water Quality Monitoring, Information, and Restoration Act. DEQ conducted water-quality monitoring from 2003-2008 at 4,573 stations, including measurements for temperature, pH, dissolved oxygen, specific conductivity, salinity, nutrients, bacteria, metals, pesticides, herbicides, and toxic organic compounds. In total, 687 different parameters were sampled for a total of 1,469,474 data points. The report also includes monitoring results from Virginia's estuarine probabilistic monitoring module that was initiated in 2000. Through this module, about 35 sites were sampled from 2000 to 2004 from Virginia's portion of the Chesapeake Bay mainstem and the tidal portions of its major tributaries. Water column parameters measured included temperature, pH, DO, salinity, PAR profiles, chlorophyll, nutrients, suspended solids, and bacterial and chemical contaminants (see also *COLO—Sediment contaminants*). Lastly the report includes results of beach and citizen water quality monitoring programs. GIS data are available for download, as well as printable maps for the York, James, and Potomac River basins.

<u>Submerged habitats and biological communities</u>

Seagrass distribution

The Virginia Institute of Marine Science has produced periodic maps of submerged aquatic vegetation (SAV) in Chesapeake Bay and the Maryland coastal bays since 1986[151, 152]. Mapping data are compiled in reports representing one year of coverage. Annual coverages and reports have been produced since 1997, and individual coverages exist also for 1986, 1989, 1991, 1992, 1994, and 1995. The reports (e.g., Orth et al. 1998, 1987) describe the boundaries and density classes of mapped SAV each year. Data from 1974 to 1990 are compiled into a single coverage. SAV was mapped through interpretation of 1:24,000 scale aerial photographs.

Biological communities and species inventories
An Environmental Sensitivity Index atlas was developed for Virginia, which contains a digital geodatabase on biological resources sensitive to oil spills[140] (see *National and Regional Datasets*).

Gap Analysis and Recommendations – Prioritization for Data Acquisition

We analyzed existing oceanographic and physiographic data and information products in terms of their quality and extent relative to park needs. Data on submerged habitats and biological communities were too disparate to fit within the scope and context of this analysis. For this data type, a higher-resolution analysis focused within similar habitats (seagrass beds, wetlands) or taxonomic groupings (shellfish, anadromous fish, other faunal communities) would be most useful.

Table 16 provides a comparative rating of the oceanographic and physiographic data available for each NER park. Data were ranked as fully sufficient, intermittent, or insufficient for meeting park needs. Ranking criteria varied among data types, but generally included the amount of data falling within park boundaries, the resolution of the data, and the overall relevance to park interests; criteria specific to each data type are described within the respective sections below. This analysis revealed the primary gaps in available data to fall within the bathymetry and surficial geology data types; overwhelmingly and uniformly across all parks, the most pressing needs are for consistent, high-resolution bathymetry and seafloor characterization data. Recommendations for data acquisition to fill gaps in existing data are summarized within individual data types below. Full descriptions and references for datasets and information sources are included in the Summary of Existing Data section and generally are not repeated here. References to specific datasets are included in this section in rare instances, for emphasis or purposes of clarity.

Our gap analysis focused on the geographic coverage of data within park boundaries. In certain cases, comprehensive and integrated management of the parks' marine resources will also require data from areas adjacent to or outside of park boundaries. Needs for bathymetry, seabed characterization, and other resource data collected outside of park boundaries will vary by park. Park-specific management objectives and regional geomorphologic variations influence the geographic scope of data needs that are external to the park. For example, we included bathymetric, hydrogeologic framework, and other data for shoals occurring as far as 20 km offshore of ASIS park boundaries because: (1) the shoals influence geomorphology within ASIS park boundaries; and (2) sand replenishment efforts include sand-bypassing from these shoals to nearshore areas within the park. Dynamic sediment transport is but one example of a feature that may increase a park's need for data from outside of its boundaries.

Table 16. Qualitative rating of existing data available for each park by data type. 0= insufficient to no data meeting the analysis criteria for this data type; 1=intermittent data extent or quality; 2= likely fully sufficient in meeting the analysis criteria for this data type and NER priority data needs.

Data Type	GATE	CACO	ASIS	FIIS	BOHA	COLO	GEWA	ACAD	SAHI	SAIR
Bathymetry	1	1	1	1	1	0	0	0	0	0
Hydrography	1	1	1	1	2	2	1	1	1	1
Hydrogeologic Framework	2	2	2	2	2	2	2	2	2	1
Surficial Geology	1	0-1	1	1	1	0	0	0	0	0
Sediment Contaminants	1-2	1	1-2	1-2	1-2	1	1	1	1	1-2
Water Quality/ Water Chemistry	2	2	2	2	2	2	2	1	2	1

Bathymetry Data Gap Analysis

Bathymetry and seafloor topography data are deemed some of the most critical of the NER high priority data types; these data provide essential baseline information and form the framework for the study and comprehension of other ecosystem components. Roworth and Signell (1998) stated that "a system-wide description of the seafloor topography is a basic requirement for most coastal oceanographic studies." Due to the importance of this data type, the sum total of bathymetric data available for an individual park received a high rating in our analysis only if they were relatively current (post 2000), high-resolution (i.e., consistent with resolutions achieved with acoustic instrumentation), and continuous (i.e., complete ensonification) across nearly the entire extent of the park's sub-tidal area. Only those park datasets meeting these stringent criteria would receive the highest "2" rating in Table 16.

The following sub-sections analyze the sufficiency of bathymetry datasets available for each park in meeting the rating criteria. Overall, while a number of parks have significant bathymetric datasets, none of the parks' bathymetric and seafloor topographic datasets achieved the highest rating. Note that these ratings are based on datasets available at the time of the inventory's completion (and some acquired post-inventory), and therefore may not represent current status. Overall, ASIS, GATE, and FIIS benefit from substantial high-resolution coverage, while less comprehensive bathymetric data are available for sub-tidal extents of CACO and BOHA. Insufficient high-resolution coverage currently exists for sub-tidal areas of ACAD, GEWA, COLO, SAIR, and SAHI.

GATE

New, high-resolution acoustic data is due to be published by the State University of New York (SUNY) at Stony Brook covering areas deeper than 0.5 m within the bayside extent of GATE's Jamaica Bay section. Further assessment of available lidar data is needed to determine the extent to which these data fill gaps in coverage from shore out to 0.5-m depths. Flood et al. (2008) suggest that the 2006 NOAA Coastal Services Center/U.S. Army Corps of Engineers lidar surveys failed to map water depths even in shallow water due to turbidity. Regardless, current high-resolution bathymetry for Jamaica Bay nears full coverage. In contrast, bathymetry data for the Sandy Hook and New York/Raritan Bay sections of the park are older and represent more limited geographic coverage. For example, the NOAA Estuarine Bathymetry Project[234] map for Raritan Bay represents pre-1988 sounding data that has been interpolated to provide full coverage of the bayside extents of the Sandy Hook, Raritan Bay/NY Harbor, and Jamaica Bay sections of the park. Similarly, autonomous underwater vehicle (AUV) surveying by Rutgers University represents modern mapping of shallow extents of the park, but covers only a portion (1.4 km by 0.25 km) of the Sandy Hook section of GATE. Minimal and/or dated bathymetry is available for the nearshore oceanside areas of the park. High-resolution bathymetry surveying is recommended for shoreface areas of the park, for the NY Harbor/Raritan Bay section, and remaining areas at Sandy Hook.

ASIS

Bathymetry mapping within ASIS includes recent, high-resolution surveys for extents of the park. NOAA NOS (2008b) multibeam surveys provide high-resolution, accurate, 100% coverage bathymetry along half of the seaside length of the park in areas deeper than about 3 m. Modern, high-resolution acoustic surveys also cover bayside, inlet, and oceanside areas at the very northern end of ASIS. Post-2000, single-beam surveys cover areas deeper than 2 m within the Maryland Coastal Bays and areas deeper than 0.5 m in the Virginia section of Chincoteague Bay. In addition to these surveys, the NOAA NGDC digital elevation model for Ocean City and vicinity compiles datasets representing a large range of dates, survey instruments, and data resolutions to provide seamless coverage of all terrestrial and submerged areas within the park. High-resolution lidar data from NOAA CSC and USGS have also been collected over the entire extent of the island's terrestrial, shoreline, and intertidal area, although these data cover limited sub-tidal area (depths less than 5 m). Additional annual lidar surveys have been conducted in the northernmost extent of the park. These lidar data serve to bridge mapping of the terrestrial and submerged realms and aid the creation of digital elevation models (DEMs) that extend from land to water. Lastly, bathymetric data exist for shoals offshore of ASIS that have the potential to contribute sand resources to the park.

While bathymetric coverage of ASIS is significant, additional high-resolution, continuous coverage mapping is recommended along the southern shoreface of ASIS and to fill any gaps that exist between lidar coverage and recent NOS multibeam surveys in seaside areas along the northern half of ASIS. The highly mobile substrates that characterize this park will also necessitate ongoing re-surveying to assess bathymetric changes.

CACO

The MA CZM bathymetry mosaic represents the most comprehensive compilation of bathymetric data available for the state as of 2008. The mosaic compiles data of varying resolutions to cover the entire geographic extent of the park with no known omissions. This dataset was not further analyzed to discern the dates, resolutions, and coverages represented by the individual datasets incorporated into this mosaic. Finer resolution of the boundaries of inshore areas was achieved through the USFWS Gulf of Maine bathymetry map, but the map does not include absolute elevations and therefore has limited immediate value for bathymetric assessment. Pre-2000 USGS and MassGIS bathymetry grids for the Gulf of Maine region compile and interpolate older datasets of varying resolutions and spatial coverages. High-resolution acoustic swath bathymetry is available for a number of small sections of the Cape Cod Bay section of CACO totaling less than 2.5 km^2. A compilation of 1998 to 2008 multibeam, hydrographic, and satellite data represents variable resolution coverage for an approximate 8 km by 1 km extent at the southern end of the park. Additionally, NOAA Coastal Service Center 2007 coastal lidar provides high-resolution, continuous coverage data for terrestrial and intertidal areas of CACO, and potentially out to 1500 m from shore where depth and water clarity allowed. While further analysis is needed of actual sub-tidal coverage achieved by this survey, these lidar data serve to bridge mapping of the terrestrial and submerged realms and aid the creation of DEMS that extend from land to water.

While relevant and current bathymetry data exist, there remains a need for complete ensonification, high-resolution surveys for extents of CACO's sub-tidal area. Furthermore, the mobility of substrates in this barrier island system will necessitate ongoing bathymetric re-surveying.

FIIS

Bathymetry data for FIIS includes modern acoustic coverage for portions of bayside and oceanside extents of the park. SUNY Stony Brook's model domain and gridding effort provides modern multibeam data for the majority of Great South and Moriches Bays, as well as an interpolated bathymetry map that covers the entirety of FIIS sub-tidal areas through the merging of bayside multibeam data with existing NOS hydrographic survey data. Additional localized datasets for FIIS include: (1) high-resolution, sub-centimeter accuracy interferometric survey data collected in very shallow waters (0.8 m to 3 m) within two small areas of Great South Bay (less than 1 $km^{2)}$; (2) a dated bathymetry contour grid for the entire oceanside length of FIIS from the 8 m isobath to 10 km offshore; and (3) recent single-beam and multibeam surveys out to 4 km offshore in depths 0 m to 10 m along two 4.5-km stretches of the Fire Island shoreface. Pre-1960s hydrographic sounding data provide older, lower resolution bathymetric coverage of Great South Bay. Additionally, NOAA CSC 2006 coastal lidar provides high-resolution, continuous coverage data for the terrestrial and intertidal areas of FIIS, and potentially out to 1500 m from shore where depth and water clarity allowed. While further analysis is needed of actual sub-tidal coverage achieved by this survey, these lidar serve to bridge mapping of the terrestrial and submerged realms.

In total, the bathymetric datasets available for FIIS represent high-resolution, high quality coverage of substantial bayside extents and small areas of shoreface coverage, as well as older (1990s) non-continuous coverage of oceanside areas beyond the 8 m isobath. The greatest needs for bathymetric mapping at FIIS remain along the shoreface exents of the park. These needs are being addressed by bathymetric and EAARL lidar surveys being completed by USGS and Coastal Carolina University in 2011 from wave breaking depths to about 10 km offshore of the FIIS seashore. When products from this survey are available, FIIS bathymetry data availability will be sufficient to receive a "2" rating for this data type. As with the other predominantly barrier island parks, the mobility of substrates at FIIS will necessitate ongoing bathymetric re-surveying.

BOHA

Several localized high-resolution bathymetry datasets exist for the Boston Harbor area as a whole, but very little coverage exists within sub-tidal extents surrounding BOHA's managed islands. Post-2000 multi-beam bathymetry surveys abut, but do not fall within park boundaries. Digitized chart data for Boston Harbor includes only channel areas deeper than 10 m, and pre-1970 NOS hydrographic sounding data for Massachusetts Bay provides dated bathymetry for waters deeper than 3 m. A number of state and region-wide compilations complement these localized datasets. The MA CZM bathymetry mosaic represents the most comprehensive compilation of bathymetric data available for the state as of 2008. The mosaic compiles data of varying resolutions (from 2 m to 90 m) to cover the entire geographic extent of the park with no known omissions. This dataset was not further analyzed to discern the dates, resolutions, and coverages represented by the individual datasets incorporated into this mosaic. Finer resolution of the boundaries of inshore areas was achieved through the USFWS Gulf of Maine bathymetry map, but the map does not include absolute elevations and therefore has limited immediate value for bathymetric assessment.USGS and MassGIS bathymetric maps for the Gulf of Maine region compile pre-2000 datasets of varying resolutions. NOAA Coastal Services Center 2007 coastal lidar provides high-resolution, continuous coverage data for the terrestrial and intertidal areas of BOHA, and potentially out to 1500 m from shore where depth and water clarity allowed. While further analysis is needed of actual sub-tidal coverage achieved by this survey, these lidar data serve to bridge mapping of the terrestrial and submerged realms and aid the creation of digital elevation models (DEMS) that extend from land to water. In summary, limited modern, high-resolution bathymetry data are available for BOHA sub-tidal areas; additional high-resolution, continuous coverage bathymetric surveys are recommended.

ACAD, SAIR, SAHI, COLO, and GEWA

In addition to datasets described in the *National and Regional Datasets* section, bathymetry data for COLO and GEWA includes 1880s to 1990s interpolated hydrographic sounding data covering terrestrial to sub-tidal extents of both parks. High-resolution interferometric datasets exist for small extents of seafloor located 2 km to 7 km from the park boundaries; and 1-m contours for the mainstem Chesapeake Bay are located 5 km -50 km from the boundaries of these parks. No post-2000, high-resolution bathymetric data are recorded in the inventory for COLO or GEWA.

Similarly, no post-2000, continuous coverage, high-resolution bathymetry data are recorded in the inventory for ACAD. ACAD is included within a USFWS Gulf of Maine bathymetry map, but the map does not include absolute elevations and therefore has limited immediate value for bathymetric assessment. Pre-2000 USGS and MassGIS bathymetry grids for the Gulf of Maine region incorporate ACAD, compiling data of varying resolution and spatial coverage collected from 1956 to 1999. Although dated, these grids provide seamless, interpolated bathymetric coverage from terrestrial to marine extents of the park. A bathymetry map of Bar Harbor compiles and interpolates older and non-continuous sounding data collected from 1946 to 1962 with an average separation of over 100 m.

SAIR is included within two pre-2000 Gulf of Maine bathymetry grids which are based on interpolated soundings.

An interpolated DEM for Long Island Sound compiles 1930s hydrographic sounding data and incorporates SAHI.

Significant additional bathymetric surveying is needed to achieve full high-resolution coverage within these parks. In summary, current, high-resolution and continuous coverage bathymetry data remains a need for these five parks.

Recommendations for bathymetry data acquisition

The highest priorities for bathymetry mapping in NER parks are shallow nearshore areas, which characterize the majority of submerged lands within park boundaries and where most data gaps exist. As a general rule, we recommend interferometric bathymetric mapping and simultaneous backscatter collection within the shallow sub-tidal areas (less than 10 m) of the NER parks. Alternatively, single-beam instruments may be deemed most appropriate for shallow water bathymetry mapping under various conditions and for individual park cases (e.g., surf zones, technological availability, funding, very shallow depths, etc.). In deeper waters (10 m to 30 m) multibeam and interferometric swath instruments will be the likely technology choices for bathymetric (and simultaneous backscatter intensity) data collection. Multibeam instruments are recommended at depths greater than 30 m. EAARL lidar surveys, especially those conducted when turbidity is at its lowest in the NER, have the potential to fill data gaps between terrestrial, intertidal, and sub-tidal data, serving objectives related to the creation of seamless park elevation models. In all cases, planning for bathymetry mapping (including choices regarding technologies, geographic coverage, resolution, target accuracies, data processing, and products) will be driven by the data objectives, intended uses, park size, terrain, and the time and resources available.

Surficial Geology Data Gap Analysis

Substrate characterization has been deemed a high priority data type by NER parks. These data also provide a guiding framework for the design of finer-scale studies (e.g., sand resources) and broad scale surveys (e.g., habitat assessments/inventories). Frequently, data relevant to substrate characterization are collected simultaneously with acoustic bathymetric measurements in the form of backscatter intensity data and are part of the integrated sampling approach described in the introduction to this report. For this reason, our rating of available acoustic seabed data mirrors the criteria used for analyzing bathymetry data. The sum total of acoustic seabed characterization data available for an individual park received the highest ranking in

Table 16 if they were relatively current (post-2000), high-resolution (i.e., consistent with resolutions achieved with acoustic instrumentation), and continuous (i.e., complete ensonification) across nearly the entire extent of the park's sub-tidal area. Additionally, we assessed if acoustic seabed data were ground-truthed and if interpretive substrate-type maps were developed to spatially display the distribution of surficial sediment types.

Grain size and organic content data that were collected for the purpose of ground-truthing acoustic or other broad-scale mapping data are assumed sufficient to meet this purpose and therefore were not analyzed further for sampling density. Grain size and organic content data collected for purposes other than ground-truthing (e.g., for fine-scale gravel and sand resource assessment) rated highly if they covered a large extent of the park's sub-tidal acreage. Sampling density of sediment samples was not compared because the criteria for what constitutes sufficient or high-quality sampling varies markedly depending on the sampling objectives, as well as the heterogeneity and variety of substrates.

Overall, while sediment grain size and organic content sampling has been conducted at varying densities in all of the parks, none of the NER parks received the highest rating for surficial geology data primarily because of insufficient acoustic seabed survey coverage and spatial product development.

GATE

At the time of this publication, SUNY at Stony Brook was in the process of publishing seabed classification products for the Jamaica Bay section of GATE, based on sidescan and multibeam acoustic mapping in all of the bay's waters deeper than 2.5 m, as well as ground-truthing grab sample data collected at 85 bay locations. Comprehensive seabed classification, geoform, and grain size distribution maps are some of the proposed products of this effort. The project will provide high-resolution acoustic seabed characterization, ground-truthing, and interpretive products for all but the shallowest extents of Jamaica Bay. The project also provides an example for park units wishing to apply the CMECS classification scheme. Current, high-resolution, sidescan sonar backscatter images and interpretative products are also available for a very shallow section of GATE's Sandy Hook section measuring less than 1 km^2. Extensive sidescan sonar coverage was achieved throughout the New York Bight region in 1995 to 1996, but the dataset does not overlap park boundaries. Acoustic seabed characterization, ground-truth data, and related interpretive substrate characterization maps for GATE are thus limited to Jamaica Bay and a small extent at Sandy Hook. Coverage of the Raritan bay section of GATE is lacking.

Sediment grain size and organic content data collected for purposes other than ground-truthing further enhance surficial geology information available for this park. The 2005 Atlantic coast usSEABED database improves upon the older and sparser sediment data compilations represented by CONMAP and the East Coast Sediment Texture Database. Representing a compilation of studies from different time periods, this dataset does not provide a single temporal snapshot of sedimentary character in the park. Sediment data samples covered in this database provide sediment character information for both oceanside and bayside areas within the three sections of the park. The spatial density of the sample points varies markedly within the park boundaries, with the highest number of samples in the Jamaica Bay section of GATE. Pre-2000 datasets from REMAP and the U.S. Army Corps of Engineers/NOAA Coastal Services Center provide additional, but dated, sediment grain size and organic content information for the three sections of the park.

Overall, substrate characterization data available for GATE received an intermediary rating. Seabed characterization data and interpretive maps based on acoustic backscatter and ground-truth data are available primarily for Jamaica Bay. Additional acoustic seabed characterization and ground-truthing is recommended within the NY Harbor/Raritan Bay section and in remaining areas of the Sandy Hook section of GATE. Grain size and organic content data of varying sampling densities and temporal profiles exist for all sections of GATE within both bay and oceanside areas, and are assumed of sufficient sampling density to meet their intended purposes. Additional sediment sampling, especially within the Sandy Hook and Raritan Bay sections of GATE, may be necessary to meet specific park objectives for surfacial sediment characterization.

CACO

Acoustic characterization data for CACO consists of one multibeam backscatter study overlapping three small sections of the northern bayside extent of the park. The data were collected pre-2000 (1998), but represent high resolution backscatter intensity measurements of seafloor hardness and roughness. The data were ground-truthed and interpretive surficial sediment distribution maps were developed as a part of this USGS mapping project. No other acoustic characterization data for CACO were recorded in the inventory, leaving a void of coverage and spatial products for the large majority of the park's subtidal area.

Sediment grain size and organic content studies pertinent to CACO include sediment sampling of varying densities within seaside and bayside extents of the park. Sampling density for fine-scale studies varies markedly throughout the park. The 2003 USGS surficial sediment GIS compilations for the Gulf of Maine and Cape Cod Bay region display the densest sampling coverage in the northern seaside and bayside areas of the park and sparser coverage within the southern seaside areas of the park. Many of the data sources incorporated into these compilations are pre-2000 and, because they represent a compilation of studies overtime, these datasets do not provide a single temporal snapshot of surface sediment character in the park. The remaining sediment grain size and organic content data for CACO include post-2000 information from intertidal areas within two areas of the park and pre-1992 data compiled for the western Gulf of Maine. Additional grain size and organic content sampling may be needed to meet specific park objectives.

FIIS

Shumchenia and King (2010) achieved sub-centimeter resolution of seabed features of two small sections within Great South Bay through acoustic backscatter intensity and ground-truth surveys. Products included a sidescan mosaic and an interpretive sediment distribution map. This study characterized benthic habitat according to the CMECS system and may be of interest to those parks intending to utilize this classification approach. The project also provided technology comparisons, which may help guide the design of future seabed mapping and surficial geology characterization conducted within NER parks. Also focusing on bayside areas of FIIS, a project abstract describes side-scan and multibeam backscatter data that were collected in Great South Bay in 2002, but it is unclear from available text sources the extent of coverage, if ground-truthing was conducted, or if substrate characterization products were developed from these data (Clapp and Flood 2004). Backscatter images and interpretive spatial products, if developed, are not readily available from this project.

In oceanside areas, recent multibeam backscatter intensity imagery has been produced for two 4.5 km stretches extending from 1 km to 4 km offshore, but these data fall outside of the park boundary that extends only about 300 m seaward from the shoreline. In addition, high-resolution sidescan and multibeam sonar surveys and ground-truthing conducted from 1996 to 1998 achieved 100% coverage of an area extending from the 8 m isobath to 10 km offshore along the entire oceanside length of Fire Island. A surficial sediment map and sidescan mosaic was produced from these data (Schwab et al. 2000c). While dated and mostly falling outside of park boundaries, these data provide significant surficial sediment characterization information pertinent to the FIIS area. The project produced comprehensive information about surficial sediment distribution, sand wave geomorphology, and sediment transport dynamics in the vicinity of FIIS. In summary, only limited ground-truthed, acoustic seabed characterization data exists for FIIS. Significant additional backscatter intensity surveys, ground-truthing, and interpretive product development are needed within both bayside and oceanside extents of the park.

Sediment grain size and organic content data collected through fine-scale studies provides further information about the character of the park's surficial substrates. The 2005 Atlantic coast usSEABED database improves upon the older and sparser sediment data compilations represented by CONMAP and the East Coast Sediment Texture Database. Sediment data samples contained in this database provide sediment texture and lithology data and other sediment attribute data for both oceanside and bayside areas of FIIS. The USGS Marine Aggregate Resources Project project compilation of usSEABED data for the New York/New Jersey area contains nearly 50 points within the FIIS boundary. The spatial density of the sample points varies markedly throughout the park, with the majority of the samples occurring above the shoreline (beach samples), and the highest density of sampling points located sub-tidally near the mouth of Moriches Bay. The SEABED extracted (numerical) dataset for the Atlantic region contains another 90 sampling points, distributed primarily within Great South Bay. Composed of samples from different time periods, these compilations do not provide a single temporal snapshot of sedimentary character within FIIS. Interpretive sediment distribution maps were developed from the usSEABED data in 2003. Other sediment grain size data for FIIS consists of pre-1980s textural descriptions. Overall, sediment grain size data for FIIS are available for both bayside and seaside extents of the park. The density of this data is assumed to be sufficient for their intended purpose, but denser sampling may be required to meet the park's specific goals for surficial sediment characterization.

Overall, substrate characterization data available for FIIS received an intermediary rating. Additional high-resolution acoustic seabed characterization surveying and corresponding groundtruthing is recommended on the shoreface of FIIS to fill gaps between the shoreline and the 8 m isobath. Within bayside areas, additional acoustic seabed mapping is recommended to fill existing gaps. Additional fine-scale sediment grain size data may be useful for sediment characterization efforts at FIIS.

ASIS

Acoustic characterization data recorded within the inventory for ASIS include sidescan sonar images from a single study covering the Virginia shoreface section of the park. Products of this study include sidescan sonar images, but not interpretive maps of surficial sediment distribution. In addition to this record within the inventory, two additional backscatter intensity surveys were located during the writing of this report. Conducted by NOAA NOS in 2008, these surveys cover approximately half of the northern shoreface section of the park. While bottom samples were collected for ground-truthing, interpretive maps of surficial sediment distribution were not readily available. In summary, acoustic backscatter intensity data exists for the shoreface section of ASIS, but surficial sediment maps are recommended as a product of these data. Acoustic seabed surveying is needed within bayside sections of the park and to fill gaps in shoreface sections of the park.

Grain size analyses conducted for purposes other than ground-truthing of acoustic data include both bayside and oceanside sediment bottom samples. Localized studies within the coastal bays acquired hundreds of bottom sediment samples within the ASIS bayside boundary during the 1990s and 2000s. Detailed sediment grain size distribution maps were produced from these studies. These localized sampling studies are further bolstered by national datasets. The densest sampling within the ASIS seaside section has been conducted in association with the North End Restoration project along the northern portion of the island. In addition, national and regional compilation datasets report sediment grain size and organic content sampling of varying densities along the length of the ASIS shoreface. Overall, the most comprehensive fine-scale analyses of sub-tidal surface sediments in the park exist for bayside and northern seaside portions of ASIS.

Surface substrate data evaluated for ASIS were given a “1” rating due to insufficient acoustic seabed survey coverage particularly in bayside areas of the park and additional needs for acoustic seabed interpretive products that spatially characterize seabed sediments within the park.

BOHA

A single post-2000 sidescan sonar survey is recorded in the inventory for BOHA. This survey provides surficial sediment and acoustic seabed characterization data for the Boston Harbor region, notably including areas surrounding or abutting a number of BOHA islands and encompassing small portions of the park. The acoustic data was ground-truthed and spatial interpretive products were produced from these data including backscatter intensity, shaded-relief topography colored by backscatter intensity, and seafloor geology maps. A second and older sidescan sonar survey was located during the writing of this report, which outlines the surficial sediments of the Boston Harbor estuary. Current acoustic substrate characterization data for BOHA, therefore, includes high-resolution information for some small portions of the park, as well as significant areas surrounding the park. Additional acoustic seabed surveying, ground-truthing, and interpretive products are recommended in the remaining sub-tidal areas.

Sediment grain size and organic content data collected for purposes other than ground-truthing provide some further surficial geology information for this park. The Contaminated Sediments Database for the Gulf of Maine provides a synthesis of existing sediment data in the Boston Harbor region, although none of the sample points fall directly in the park. CONMAP includes a map of Shepard Sediment Classifications for Boston Harbor, but the classification is based on older data and only small areas of the classification polygons fall within park boundaries. Other sediment and grain size databases provide a limited number of grain size samples within park boundaries. Overall, while abundant fine-scale sediment sampling has occurred within Boston Harbor, many of these data are dated, sparse, or located outside of park boundaries.

Overall, substrate characterization data available for BOHA received an intermediate rating. Additional acoustic seabed characterization and ground-truthing is recommended within park boundaries. Improved grain size and organic content sampling densities may be necessary to meet specific park objectives for surfacial sediment characterization.

ACAD

Acoustic substrate characterization data for the ACAD region consists of two compilations of pre-2000 sidescan survey data. The sidescan survey data were groundtruthed and interpretive surficial geology maps of bottom sediment types in the ACAD region were produced from these data. While dated, these compilations provide high-resolution information about the character of bottom sediments in the ACAD region.

Sediment samples collected to groundtruth these sidescan data are deemed sufficient to meet intended purposes. Surficial samples collected for reasons other than groundtruthing include only a small number of sampling sites within park boundaries; however, hundreds of bottom sediment samples have been collected from seafloor areas within a number of km of the park boundaries.

Overall, surface sediment data for ACAD received an insufficient rating in our analysis. Existing sidescan sonar data and interpretive products are dated and grain size data collected for purposes other than groundtruthing of acoustic data included a very small number of sampling points within park boundaries. While sampling sites outside of park boundaries are numerous and provide information relevant to park management, additional grain size and organic content studies may be necessary to meet park objectives. Additional acoustic seafloor surveying is recommended to provide a current characterization of surficial sediments in the park.

SAIR

Surficial geology data available for SAIR received an insufficient rating in our gap analysis because no acoustic seabed characterization datasets are recorded in the inventory for this park. Similarly, none of the sediment grain size or organic content sampling sites recorded in national and regional datasets overlap with park boundaries.

SAHI

Surficial geology data available for SAHI received an insufficient rating in our gap analysis because no acoustic seabed characterization datasets are recorded in the inventory for this park. Similarly, none of the sediment grain size or organic content sampling sites recorded in national and regional datasets overlap with park boundaries.

GEWA

Surficial geology data available for GEWA received an insufficient rating in our gap analysis because no acoustic seabed characterization datasets are recorded in the inventory for this park. Similarly, none of the sediment grain size or organic content sampling sites recorded in national and regional datasets overlap with park boundaries. While the Maryland Geological Survey and VIMS collected and analyzed thousands of surface sediment samples in the Chesapeake Bay region, none of these points are within proximity of the park.

COLO

The inventory lists post-2000 sidescan and groundtruth data that are generally relevant to the York River area, but these data were collected several km away from COLO park boundaries. No current acoustic seabed characterization data in the inventory are located within park boundaries.

Some sediment grain size samples from the Virginia Department of Environmental Quality 303d integrated assessment were collected within park boundaries. Other sediment sampling data recorded in the inventory are dated and/or located outside of park boundaries. Taken together, the national, regional, and localized sampling that has been conducted in the York and James Rivers provides relevant information about the general character of surficial sediments in the vicinity of COLO; however, limited current sampling has been conducted within COLO boundaries. It should be noted that a report located post-inventory (Harris et al. 2010) uses the grain size data reported in this inventory (e.g., Byrne et al. 1980) to provide additional grain size distribution analyses for the Chesapeake Bay region, including COLO.

Acoustic seabed characterization, sediment grain size, and organic content data available for COLO received an insufficient rating in our analysis.

Recommendations for surficial geology data acquisition

Significant grain size and organic content data have been collected along the eastern seaboard via fine-scale studies, and in cases these data have been mapped, interpolated, and classified to develop surficial sediment distribution maps relevant to NER parks. These data and maps represent a vital source of geophysical seabed and habitat information for the parks. The sampling densities represented by these studies were determined to meet specific survey objectives and may or may not be sufficient to meet objectives outlined by the parks.

While fine-scale sampling data are available at varying densities within all of the parks, acoustic seabed characterization products relevant to the NER parks are largely lacking or provide insufficient coverage. Acoustic seabed mapping provides higher resolution continuous coverage data over larger areas than can normally be achieved through fine-scale studies, and, as such, has been deemed a priority data type for marine management within the parks. Development of acoustic seabed characterization maps can be hindered by the expense, processing time, expertise, technological availability, and ground-truthing associated with acoustic mapping of surficial geology. While vital, this may be the most difficult of the priority data types to achieve. We recommend inter-park planning to define efficiencies that can be accomplished through cooperation on acoustic seabed characterization within park boundaries. These efficiencies may include, but not be limited to, shared funding mechanisms, expertise, and technology.

As acoustic surficial geology data acquisition is part of the integrated sampling approach described in this report, our technological recommendations for acquiring these data are similar to those described for bathymetry data acquisition. In the name of efficiency, we recommend simultaneous backscatter intensity and bathymetry data collection whenever possible. Interferometric instruments may be the technology of choice for gathering acoustic backscatter data in sub-tidal areas less than 10 m due to superior swath widths achieved at shallow depths and simultaneous bathymetry data collection. AGDS systems may also be an appropriate choice for acquiring acoustic signature data in very shallow waters. Although not sufficient for bathymetric mapping, sidescan sonar instruments provide high-resolution backscatter intensity data, are unmatched in their object detection capabilities, and can be mounted on traditional survey vessels as well as AUVs that can operate at shallow depths. Multibeam instruments provide simultaneous backscatter intensity and bathymetry data, and achieve sufficient swath widths in waters greater than 10 m. Multibeam instrumentation is optimal at depths greater than 30 m. Ground-truthing acquired after acoustic surveying may be targeted specifically and efficiently to verify the boundaries and substrate classifications inferred from acoustic signatures. In-survey ground-truth sampling, however, can take advantage of funded and established vessel survey time.

Hydrography Data Gap Analysis and Recommendations

Wave forecast maps and tidal predictions are available for all NER park estuaries from NOAA National Weather Service and National Ocean Service programs. These modeled hydrographic data provide a sufficient basis for many routine needs, including preliminary site evaluations and vulnerability assessments. However, design and implementation of management activities will typically require high resolution, local hydrographic information. In addition to model projections, moored buoys and water-level monitoring stations provide reference data at specific locations. We ranked the overall availability of hydrographic data for each park based on the location of existing monitoring stations relative to park boundaries and the number of parameters measured (Table 16). Parks received the highest rating "2" if there was at least one fixed tide-monitoring station and one moored buoy providing wave data within 20 km of the park and within the same body of water; only two parks fell in this category (BOHA and COLO). A rating of "1" signifies the availability of only one category of hydrographic monitoring data (waves or tides) in close proximity to the park. The remaining NER parks fell in this category (

Table 16); tidal monitoring data are available for all of these parks, but real-time wave data are lacking. Given the availability of sophisticated hydrographic model forecasts applicable to all parks and the existence of tidal data in relatively close proximity, no park received a "0" or insufficient ranking. In general, the modeled and collected hydrographic data already available are likely to meet many park needs. If highly site-specific tide data are required for individual engineering, restoration, or management projects, temporary water-level recorders can be installed at fairly low cost. However, we recommend parks partner with NOAA National Ocean Service for installing tide gauges for regular, uninterrupted water level measurements over long periods while maintaining a stable elevation reference relative to a tidal datum. Dr. Jeffrey Cross, Chief of NPS Ocean and Coastal Resources Branch, reported that NPS is working on an interagency agreement with NOAA Center for Operational Oceanographic Products and Services to establish such tide gauges in park waters (electronic communication 9-20-2012). If site-specific wave data are required then we recommend parks partner with the applicable member of the Integrated Ocean Observing System (NERACOOS or MARACOOS) to tailor products to park-specific needs.

Hydrogeologic Framework Data Gap Analysis and Recommendations

Data on shallow subsurface sediment characteristics within subtidal regions of coastal parks are generally collected as part of an integrated acoustic and discrete sampling survey used to describe the seafloor. Therefore, gaps in available data on shallow stratigraphy parallel those described above for surficial geology and are not repeated here. The availability of data relative to remaining needs for park hydrogeologic framework (Table 2) was ranked according to the extent and types in proximity to NER parks (Table 16). The highest rating "2" was achieved if the NPS GRI determined that bedrock geologic maps were adequate for park needs, plans were made to meet outstanding geologic needs (e.g., coastal geomorphology), and in addition to USGS surface-water data, groundwater flow models have been developed or groundwater resources have been otherwise described. The majority of parks fell in this category. Only one park, SAIR, received an intermediate rating of "1". Although geologic maps and surface-water flow data are available for SAIR, groundwater resources specific to this area have not been described. Expertise to generate this information resides in the Massachusetts USGS office, which has produced similar information relevant to BOHA (Masterson et al. 1996) and CACO (Masterson 2004).

Sediment Contaminants Data Gap Analysis and Recommendations

All NER coastal parks have available coarse-scale data on sediment contaminants collected through EPA NCA and NARS programs. Although relatively few NCA and NARS sampling stations fall within park boundaries proper, these programs do provide information on the broad spatial distribution of a large number of chemical constituents in the sediments and sediment toxicity. The results of these evaluations may be used to identify the most polluted marine and estuarine areas within the northeast coastal region and guide fine-scale surveys within park boundaries. Therefore, all parks received at least a “1” ranking for this data type. Higher-resolution sampling of sediment contaminants has occurred within and adjacent to a number of NER coastal parks; these parks (GATE, ASIS, FIIS, BOHA, and SAIR) received a moderately high ranking of “1-2” due to the existence of additional sediment-contaminant data at higher sampling density. However, none of the NER coastal parks have had comprehensive (i.e., including a full suite of organic and inorganic chemical contaminants), high-resolution sediment contaminent surveys within park boundaries. Therefore, no park received a rating of fully sufficient for this data type. Ideally, acquisition of sediment samples for contaminant analyses could be integrated with discrete sample collection for ground-truthing acoustic seabed surveys. Such data acquisition would take advantage of funded and established vessel time, appropriate sampling devices for local bottom sediments, and sample collection. Additionally, because concentrations of contaminants in sediments are controlled strongly by sediment grain size and organic content (Chapman and Wang 2001), integration of contaminant assessments with surface sediment surveys assists with interpretation of sediment contaminant data. In 2010, NPS cooperated with EPA to collect NARS samples at about 60 locations in parks in Lake Michigan and Lake Superior, and there is a possibility that similar collaborations could be extended to other networks (Eva DiDonato, NPS Ocean and Coastal Resources Branch, Marine Pollution Ecologist, email communication 10-5-2012). Methods for collecting and field processing of sediments for chemistry and toxicity testing are included in Strobel and Heitmuller (2001).

Water Chemistry and Water Quality Data Gap Analysis and Recommendations

All NER coastal parks have water-chemistry and water-quality data available that are relevant to park estuaries and bays. The majority of data on water chemistry and water quality within coastal waters of NER parks is collected through the NPS Vital Signs Monitoring Program, although this type of monitoring is not implemented in all of the NER coastal parks. Parks received the highest ranking of “2” for availability of this data type if they receive regular Vital Signs monitoring of coastal waters (GATE, CACO, ASIS, FIIS, COLO, and GEWA) or if non-NPS water quality monitoring programs exist that achieve high spatial and temporal resolution in park waters (BOHA through MWRA monitoring in Boston Harbor, SAHI through Friends of the Bay monitoring in Oyster Bay/Cold Spring Harbor). For most water-quality metrics, ACAD and SAIR rely primarily on regional water-quality monitoring implemented in state waters (NARS), with relatively few sampling stations falling within or adjacent to park boundaries; these parks received a “1” ranking for intermittent data. Extending NPS Vital Signs monitoring of coastal waters to these parks would allow acquisition of high-resolution data that are regionally consistent.

Next Steps

In this document, we have identified and described the subtidal datasets that are available for each of the 10 NER coastal parks and assessed their sufficiency in meeting the parks’ high priority data needs. A primary objective of this document was to provide the parks with an assessment of data gaps and to recommend priorities for addressing existing data needs. This report provides a detailed analysis of data availability and data quality toward that end. The development of a geospatial database or spatial index of available data is recommended to guide future planning, mapping, and inventory and monitoring efforts focused on the subtidal realm. For example, a geospatial database (NOAA NCCOS 2012) and accompanying gap analysis (Dorfman and Battista 2012) were recently completed for selected Pacific and Caribbean units of the National Park Service. Integration of the datasets described in this report, and newer datasets as they are made available, within such a spatial framework would complement our analysis by enabling the parks to visualize the spatial extent of available data and their level of overlap with park coverages.

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Appendix 1. Marine Habitat Classification Schemes

NOAA Classification Scheme for Mapping the Shallow-water Coral Ecosystems of Southern Florida

A hierarchical classification scheme was developed to define and delineate the benthic habitats associated with shallow water (generally less than 30m depth) coral ecosystems of southern Florida (NOAA NOS 2008a). This classification scheme defines benthic habitats on the basis of three primary attributes: large “geographic zone” which indicates the polygon location with reference to the common cross-shelf geographic features (e.g., fore reef, reef crest, back reef, lagoon, etc.); “biological cover” which indicates the predominant biological component colonizing the surface within that habitat area (e.g., live coral, seagrass, annelid reef, etc.; and, “geomorphological structure” which indicates the physical nature of the substrate within that habitat area (e.g., unconsolidated sediment, coral reef, hard bottom, etc.). Both the Biological Cover and Geomorphological Structure classifications can have one or more sub-classifications or descriptors that further define the specific habitat type.

NOAA’s Coral Ecosystem Classification Scheme was applied to map shallow water coral reef areas in South Florida, the Caribbean, the main Hawaiian Islands, American Samoa, Guam, the Commonwealth of the Northern Mariana Islands, and Palau. Several NPS units are included in NOAA’s mapping efforts within these areas including the Virgin Islands, Buck Island Reef, Biscayne National Park, Dry Tortugas National Park, the National Park of American Samoa, War-in-the-Pacific National Memorial Park, and others.

NOAA National Estuarine Research Reserve System Classification Scheme (NERRSCS)

The National Estuarine Research Reserve System (NERRS) is a network of 27 protected areas around the U.S. established for long-term research, education and stewardship. Recently, the NERRS has developed a habitat classification scheme to facilitate the tracking of habitat change in these systems, and to link observed habitat changes to watershed land-use practices (Kutcher et al. 2005, 2008). NERRSC was expressly designed to encompass ongoing classification efforts within the NERRS, and to comprehensively inventory and classify all land-cover types (upland, wetland and submerged). It is designed for application within a GIS, and to allow effective integration of existing data at varying scales. The NERRS scheme is largely based upon modifications to the national wetland classification system of Cowardin et al. (1979), but is expanded to include upland habitats and cultural features, and to better address marine and estuarine habitats (Kutcher et al. 2008).

The structure of NERRSC is composed of two elements, (1) a four-level hierarchy and (2) a set of non-hierarchical categories. The hierarchical element is strictly nested, with numerical coding and a columnar data format. This allows data to be queried and analyzed at various levels of interest, both within and across hierarchical levels. Non-hierarchical elements add information, or further subdivide the hierarchical elements, but without the constraints imposed by nesting. Non-hierarchical elements include both “nominal categories” and “modifiers”. Nominal categories are taken from scientific naming conventions such as a descriptor for the common habitat name or the name of the dominant species dominant species. Modifiers represent sets of attributes that can be appended to hierarchical and nominal data in a flexible manner to further describe or subdivide units or add information about cultural features.

Because NERRSCS was developed for application to estuarine reserves, it concentrates on intertidal and shallow subtidal habitats to a much greater extent than the other habitat classification schemes reviewed for this project. The 27 protected areas of the NERRS are distributed throughout the coastal states of the continental US, Alaska and Puerto Rico, and many are found in regional proximity to many coastal National Parks. Within the NPS NER, NERRS holdings are found near CACO, GATE and COLO.

U.S. Geological Survey Coastal Mapping Classification Schemes

The U.S. Geological Survey has long been involved in mapping sediments and subsurface geological characteristics of the seafloor off both the Pacific and Atlantic coasts of the United States. More recently USGS has become involved in attempting to map and classify benthic marine habitats in high priority areas in all of our coastal and marine areas. Large scale benthic habitat maps for the EEZ from California to Washington State are being developed by the USGS at this time and the USGS is working with Glacier Bay NP to produce benthic habitat maps by integrating physical structure and biohabitat information within a GIS format. The USGS Center for Coastal and Watershed Studies is also involved in an interagency effort to delineate benthic areas and topographic formations on the Florida Shelf and make such maps available to the public through a user friendly website. However, the USGS also has no standardized benthic habitat classification scheme and is only beginning to consider methods to standardize the classification and display of habitat and surficial geology information.

Cooperative USGS marine benthic mapping projects in National Park Units (e.g., Hawaii and Glacier Bay) have used a variety of mapping classifications and informational displays in the projects completed. USGS has developed high resolution bathymetric maps utilizing lidar technology in the coral reef parks, which when integrated with NOAA's benthic habitat classifications generate useful products for NPS managers. Funds from NPS NRPP, Geologic Resources Division, and Inventory and Monitoring have provided cost-share for these efforts, and park and Inventory and Monitoring staff have participated in diving and boat-based surveys.

System for Classification of Habitats in Estuarine and Marine Environments (SCHEME)

Florida has recently developed a standardized hierarchical system for classification of marine and estuarine benthic habitats that is now being used by all State Agencies and others in Florida. The highest level of classification unit within SCHEME is "Class" with each Class then being further defined by subsequent levels of Subclass designations. The Class categories are similar to the marine and estuarine classes in the widely used Cowardin classification of wetlands and deep-water habitats of the United States (Cowardin et al. 1979) and allow for crosswalk and comparison between these two systems at the Class level. SCHEME is also very compatible with NOAA's thirteen level classification system as described by Allee et al. (2000) and NatureServe's CMECS system. However both of those systems allow for mapping at geographical extents beyond Florida, such as the "Ecological Region" descriptor applied to the Regime classification within CMECS. SCHEME was developed to fit into the levels 11-13 of NOAA's thirteen level classification system.

SCHEME consists of a hierarchical structure with five levels (Class and four possible Subclass designations with two lists of modifiers (General and Taxonomic) applied to each of the appropriate levels. There are currently seven Class level designations within SCHEME predicated on a general category of bottom types ranging from “Unconsolidated Sediments” through “Submerged Aquatic Vegetation” to “Reef/Hardbottom,” “Tidal Marsh,” “Tidal Swamp,” “Land,” or “Unknown.” Class level mapping within SCHEME can be applied without detailed field measurements. Subclasses define habitats with finer resolution descriptions and geographic extents that require field measurements for verification. Although SCHEME appears to be a very robust and good classification system for Florida, it is not designed to be applied on a nationwide scale and therefore is not a likely candidate for adoption as the national standard and could not presently be easily used for park units outside of Florida.

SCHEME is currently being used to classify marine habitat information along the west coast of Everglades National Park in a cooperative project between the NPS South Florida – Caribbean Network and State of Florida.

Greene Scheme and Valentine Scheme

Greene et al. (1999) developed a geologically based seabed classification scheme specifically for classifying deep-water (greater than 30 m) marine benthic habitats. Based on extensive mapping work conducted primarily in the offshore waters of California and Alaska, this scheme is GIS-compatible and generally based on geomorphology, substrate type, and textures produced by physical processes, and sessile benthic biota. The current version (Green et. al 2007) is a refinement on an earlier version (Greene et al. 1999) reviewed by Lund and Wilber (2007) for the Massachusetts CZM evaluation, but is structurally the same. Under this scheme, habitats are classified at the megahabitat, mesohabitat and macrohabitat levels, representing a hierarchy of decreasing habitat size. The Greene scheme is founded upon hydroacoustic survey technology, and the classification of broad-scale habitats is based upon the parameters of water depth, seafloor slope, and seafloor rugosity (roughness) and induration (hardness). The alpha-numeric coding system associated with this scheme consists of seven primary characters representing: 1) physiography and depth (megahabitat), 2) substrate induration, 3) geomorphology, 4) modifiers for texture, lithology, bedform and biology, 5) seafloor slope, 6) seafloor rugosity, and 7) geological unit. This classification scheme was tested very favorably in the Massachusetts CZM evaluation (Valente et al. 2007), and has since been adopted as a separate additional component (“geoform component”) within CMECS.

Analogous to Greene et al. (2007), Valentine et al. (2005) developed a geology-based seabed characterization scheme that relies heavily on hydroacoustic survey data. Valentine and colleagues used descriptive habitat classifications (and codes) with groupings based upon seabed substrate type, sediment dynamics and the degree of physical and biological complexity. This classification scheme is the product of extensive mapping efforts in the coastal and offshore waters of the northwest Atlantic and is not necessarily targeted toward, nor appropriate for, intertidal and shallow subtidal systems. Like Greene et al. (2007), this scheme is not strictly hierarchical. Rather, it defines habitats in terms of several major themes, which are in turn modified by classes, subclasses, categories and attributes. These five major habitat “themes” are (1) topographical setting, (2) seabed dynamics and currents, (3) seabed texture, hardness and layering, (4) sediment grain size, and (5) seabed roughness. Also similar to the Greene scheme, Valentine’s classification emphasizes the use of seabed dynamics, texture, and structural complexity to characterize the seafloor for the purpose of delineating major habitat types.

European Union Nature Information System (EUNIS)

EUNIS data are collected and maintained by the European Topic Centre on Biological Diversity for the European Environment Agency and the European Environmental Information Observation Network. The purpose of EUNIS is to support EU environmental reporting requirement and habitats directives, and to coordinate with an ecological conservation network (Emerald network) created by the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention). Consequently, the marine and coastal component (Davies and Moss 2004) is only a small focus of a classification scheme that has eight other main levels devoted to terrestrial habitats. Information on plant and animal communities is more fundamental to the EUNIS classification system than other schemes reviewed here. This is not inconsistent with NER needs, but the work involved with extending it to this geographic region would be better applied toward advancing CMECS.

Appendix 2. Inventory Records

ID	Name	Data Type	Date(s)
1	Blended Coastal Bathymetry from NGDC data	Raster	Best available at publication
2	Channels from NOAA Nautical Charts	Vector	2001
3	Bathymetric one meter contour interval for the Ches. Bay mainstem	Vector	1997
4	Great South Bay, NY (M050) Bathymetric Digital Elevation Model	Raster	1933-1951
5	VA Nearshore Seismic and Sidescan Sonar Lines	PDF	2005
6	Interpolated Grid of Maryland's Coastal Bay Bathymetry, based on 2000 and 2003 Bathymetry Survey	Raster	2000-2003
7	Maryland Coastal Bay Bathymetry Survey Points	Vector	2000-2003
8	Bay Contours from 1964-1966 for Sinepuxent Bay	Vector	1966
9	Bay Depths (points) from 1964-1966 for Sinepuxent Bay	Vector	1966
10	Ocean City, MD, Inlet Tidal Delta Bathymetry Grid	Raster	2004-2006
11	NOAA Wavewatch III	Website	Daily
12	National Weather Service Buoy Observation Data - Real Time and Historical	Website	1981-present
13	Historical Atlantic Tropical Cyclone Tracks, 1851-2006	Vector	1851-2006
14	ASIS Weather Monitoring Data	Reports/ database	1992-2007
15	Locations of tide gauges in bays west of ASIS	Vector	2006
16	Locations of channel markers in bays west of ASIS	Vector	2006
17	Tax ditches in Worcester and Wicomico Counties, MD	Vector	2005
18	Public Drainage Associations in Somerset, Worcester and Wicomico Counties, ND	Vector	2005
19	ASIS Waterbodies	Vector	unknown
20	Locations of freshwater ponds within ASIS	Vector	unknown
21	Locations of permanent survey stations used to monitor the water level of freshwater lakes within ASIS	Vector	2003
22	Groundwater Resources on ASIS	PDF	2002, 2004
23	VIMSWAVE - VA Inst. Marine Science Directional Wave Data	Website	1988-1993
24	New York State Area Hydrography (polygons)	Vector	2004
25	New York State Linear Hydrography	Vector	2004
26	NPS Water Resources Division River Reach File (RF3) Hydrography	Vector	2001
27	Atlantic Coast Continental Margin Mapping (CONMAP)	Vector	1962-1999
28	ECSTDB2005 - USGS East Coast Sediment Texture Database (2005)	Vector	1955-2004
29	Maine Intercontinental Shelf Sediment Data	Vector	1984-1991
30	USGS East Coast Sediment Texture Database	Vector	1967-2002
31	EPA DE/MD Coastal Bays	Vector	1993

32	Maryland Coastal Bays Sediment Mapping Project: Sediment Cores	Vector	1991-1997
33	Maryland Coastal Bays Sediment Mapping Project: RSA Sediment Size Data	Vector	1991-1997
34	SSURGO Databases for Accomack County, VA and Worcester County, MD	Vector	2005
35	Sediments of Boston Harbor	Vector	1968
36	Massachusetts Water Resources Administration Sediment Data	Vector	1993-1995
37	Digital Mapping and Characterization of Intertidal Habitats in Wellfleet Harbor, Nauset Marsh, and Hatches Harbor, Cape Cod National Seashore	Vector	2002
38	Sediment Characteristics for Goodwin and Catlett Islands, York River, VA	Vector	2002-2004
39	SSURGO Soils - FIIS	Vector	2001 - 2006
40	Sediment Characteristics for Upper Bay of NY/NJ Harbor	Vector	1994-1995
41	Sediment Characteristics for Lower Bay of NY/NJ Harbor	Vector	1994-1995
42	Chesapeake Bay Bottom Sediments	Vector	1976- 1984
43	Gulf of Maine Contaminated Sediments Database	Vector	2002
44	Maryland Coastal Bays Sediment Mapping Project: Surficial Sediment	Vector	1991-1997
45	Sediment Chemistry Analyte Concentration data from EPA DE/MD Coastal Bays program	Excel	1993
46	Non-energy resources and shallow geological framework of the inner continental margin off Ocean City, Maryland	Report	1994
47	Potential offshore sand resoures in southern Maryland shoal fields	Report	1995
48	Offshore sand resoures in central Maryland shoal fields	Report	1996
49	ASIS Geologic Resource Management Issues Scoping Summary	Report	2005
50	Overwash of North End of ASIS, March 2004	Vector	2004
51	Overwash produced by TS Ernesto (1-2) September 2006) on the North End of Assateague Island	Vector	2006
52	Overwash produced by high tides and storms on the North End of Assateague Island, November 2006	Vector	2006
53	Overwash produced by Thanksgiving nor'easter (22-23 Nov 2006) on the North End of Assateague Island	Vector	2006
54	Erosion, Overwash, and Storm Response Resources for ASIS	PDF	varies
55	Berm Alteration Resources for North End of Assateague Island	Report	varies
56	Elevation Surveys of the ASIS North End Constructed Berm Notches	Vector	2005
57	Documentation of ASIS North End Restoration Berm Reconfiguration 2002	Report	2002
58	Sediment By-Passing Events Related to the Assteague Island NS North End Restoration project	Vector	2004-2006
59	US ACE Nearshore Profile of the North End of Assateague Island	Vector	2003-2007
60	Geomorphological Monitoring Reports for Assateague Island	Report	1999-2004
61	Shorelines for Geomorphological Monitoring, Assateague Island	Vector	1994-2007
62	Micellaneous Historical Shorelines, Assateague Island	Vector	1850-2002
63	2003 Maryland, Virginia, and Delaware Coastal Bays Shoreline	Vector	2003
64	Topographic Profiles, Assateague Island	Vector	2004-2007
65	GPS and NPS Monuments for Topographic Profiles, Assateague Island	Vector	2003
66	Ocean City Inlet Jetty, Maryland	Vector	unknown

67	Rehabilitation of the South Jetty, Ocean City, Maryland	Report	1994
68	Dune Management Documentation for ASIS	Report	varies
69	Coastal Vulnerability Assessment of Assateague Island National Seashore to Sea-Level Rise	Report	2004
70	Potential Impacts of Sea Level Rise on the Beach at Ocean City, Maryland	Report	1985
71	Map of potential impacts of sea level rise on ASIS	PDF	2006
72	Historical Shorelines - Sandy Hook, New Jersey	Vector	1835-1998, incomplete
73	Shoreline Monitoring - Staten Island, New York	Vector	2005-2006
74	New Jersey DEP Shoreline Structures	Vector	1993
75	Seawall along Potomac River, VA, at GEWA	Vector	2003
76	Shellfish Stations, Boston Harbor, MA	Vector	2000
77	NOAA NMFS Water Column Properties Data, North Carolina to Maine	Website	1977-2006
78	eMOLT - Environmental Monitoring on Lobster Traps, Maine and Mass.	Website	1880-2007
79	USGS Water Data for the Nation	Website	
80	Molluscan Water Quality Monitoring Points, Maine	Vector	1995
81	Mount Desert Island, ME, Water Quality Coalition Phytoplankton Database	Website	unknown
82	Maine Outstanding Resource Waters	Website	1999
83	NPS Baseline Water Quality Data Inventory and Analysis	Report	varies
84	State of Maryland Coastal Bays Report	PDF	2004
85	Bay Water Quality Monitoring Site Locations in the MD Coastal Bays	Vector	2006
86	Water Quality Data from EPA DE/MD Coastal Bays program	Excel	1993
87	Beach Water Sampling Sites on ASIS	Vector	2000, 2003, 2004
88	Beach Water Quality Reports at ASIS	Report	1996-2006
89	Virginia 2006 Section 303(d)/305(b) Impaired Waters	Vector	2006
90	Massachusetts Water Resources Authority Environmental Quality Department Technical Reports	PDF	1991-2007
91	Chesapeake Bay Program Water Quality for the Lower James Estuary, Virginia	Website	2000-2002
92	Chesapeake Bay Observing Program (CBOS) Water Quality Buoy Data	Website	
93	Chesapeake Bay National Estuarine Research Reserve System-Wide Water Quality Monitoring Program	Website	real time
94	Baseline Water Quality Data at COLO	Vector	1994
95	Alliance for Chesapeake Bay Citizen's Monitoring Program Water Quality Data	Website	1985-present
96	New York State 2006 Section 303(d) List of Imparied/TMDL Waters	PDF	2006
97	New Jersey DEP 2006 Water Quality Monitoring and Assessment Report	Vector	2006
98	New York Harbor Water Quality Survey	Report	2004
99	New Jersey STORET sampling locations	Vector	2005
100	Friends of the Bay Water Quality Monitoring Reports – Oyster Bay/Cold Spring Harbor Estuary, New York	PDF	1999-2002

101	NPS Water Resources Division Water Quality Monitoring Stations near SAHI	Vector	2001
102	National Wetlands Inventory	Vector	Varies by Park
103	NOAA NMFS Trawl Survey Data, North Carolina to Maine	Website	1948-2005, incomplete
104	Coastal Maine SAV Data	Vector	1993-1997
105	Tidal Pools at ACAD	Vector	1999
106	Maine Eelgrass	Vector	1993-1997
107	Beginning with Habitat - water resources, riparian habitats, plants and animals at ACAD	Report	2004
108	Shellfish Habitat – coastal Maine	Vector	1994
109	Marine Worm Habitat, ACAD	Vector	1992
110	Exotic Plant Species Recorded on Assateague Island NS, 1999-2001	Vector	1999-2001
111	Loggerhead Sea Turtle Data at ASIS	Vector	1998-1999
112	Assateague Island Piping Plover Nests	Vector	1994-2006
113	Assateague Island North End Piping Plover Habitat	Vector	1994-2006, incomplete
114	Assateague Island Piping Plover Brood and Chick Range Estimates	Vector	1994, 2000
115	Marine Animal Strandings at ASIS	Report	
116	Rare Plants at ASIS	Vector	1998-2003
117	Sea Beach Amaranth at ASIS	Vector	2000-2005
118	Chesapeake Bay and Delmarva Coastal Bays Submerged Aquatic Vegetation	Vector	1974-2002
119	Submerged Aquatic Vegetation Monitoring Pilot Project Summary, 1998-2000, ASIS	Report	2001
120	Seagrass Recovery in Delmarva Coastal Bays	PDF	2006
121	Fish Data from EPA DE-MD Coastal Bays Program	Excel	1993
122	Marsh, Dune, and Forest Exclosure Locations at ASIS	Vector	1996
123	NWI Wetlands, Worcester County, Maryland	Vector	1981
124	Department of Natural Resources (DNR) Wetlands Inventory of Worcester County, MD	Vector	1989
125	Tiger Beetle Annual Reports at ASIS	Report	2001-2005
126	North End of Assateague Island Vegetation Monitoring Data and Reports	Report	1996-2003
127	ASIS Mosquito Monitoring Data and Reports	Excel	2000-2002
128	1998 Massachusetts GIS Wetlands	Vector	37104
129	BOHA Intertidal Study	Vector	2001-2003
130	2007 Massachusetts DEP Wetlands 1:12,000 Polygons	Vector	2007
131	Coastal Massachusetts SAV Data	Vector	1993-1997
132	Massachusetts DEP Statewide Eelgrass Polygons	Vector	2001
133	Massachusetts Wetland Change 2001-2005	Vector	2005
134	Shellfish Sampling Points in Massachusetts	Vector	2000
135	Anadromous Fish Points in Nashua, Concord, and Shawsheen Rivers, MA	Vector	1997

136	Fish Traps (Weirs), Massachusetts	Vector	1999
137	Massachusetts Natural Heritage and Endangered Species Program (NHESP) Priority Habitats of Rare Species	Vector	2006
138	Shellfish Suitability in coastal Massachusetts	Vector	2004
139	Designated Shellfish Growing Areas in coastal Massachusetts	Vector	2000
140	NOAA Ecological Sensitivity Index in northeastern states	Vector	Varies, 1999-2006
141	2007 MassDEP Wetlands 1:12,000 Polygons	Vector	2007
142	Digital Mapping and Characterization of Intertidal Habitats in Wellfleet Harbor, Nauset Marsh, and Hatches Harbor, Cape Cod National Seashore	Vector	2002
143	SPI Habitat Data for Goodwin and Catlett Islands, York River, VA	Vector	2002,2004
144	Benthic Infauna for Goodwin and Catlett Islands, York River, VA	Vector	2002-2004
145	Bathymetry for Goodwin and Catlett Islands, York River, VA	Raster	2004
146	Side Scan Sonar Imagery for Goodwin and Catlett Islands, York River, VA	JPEG	2004
147	Fish Species Composition in selected Streams in COLO (Paper 1)	Raster	1987
148	Fish Inventory and Baseline Water Quality of Back River system, Jamestown, VA and COLO (Paper 2)	Vector	1991
149	Fish Inventory and Baseline Water Quality of Cheatham Annex Naval Supply Center, VA (Paper 3)	Vector	1994
150	A qualitative Inventory of Fisheries Resources and Baseline Water Parameters in the Tidal Environment of COLO (Paper 4)	Vector	1998
151	Chesapeake Bay Submerged Aquatic Vegetation, MD-VA, mapped by VIMS	Vector	2005
152	Chesapeake Bay Tier I Coverage, MD-VA	Vector	1971-1990
153	Submerged Aquatic Vegetation in Great South Bay within FIIS	Raster	May - July 2004
154	Long Island Sound Benthic Habitat	Vector	2002-2003
155	Estuarine Habitats in Great South Bay, Fire Island Wilderness Area	Vector	1996
156	FIIS Vegetation Mapping Project with crosswalked NWI classification	Vector	April 1997
157	Significant Coastal Fish and Wildlife Habitats in New York State	Vector	1998
158	New York / New Jersey Harbor SPI, Grab, and Bathymetry Data Sets	Vector and Raster	1994-1995
159	Benthic Infauna for the Upper Bay of NY/NJ Harbor	Vector	1994-1995
160	Benthic Infauna for the Lower Bay of NY/NJ Harbor	Vector	1994-1995
161	Sediment Profile Images for Upper Bay of NY/NJ Harbor	Vector	1994-1995
162	Sediment Profile Images for Lower Bay of NY/NJ Harbor	Vector	1994-1995
163	Cliffwood Beach and Union Beach, NJ, Benthos	Excel	1999
164	Benthos for Port Monmouth, Union Beach, Keansburg, Point Comfort , NJ	Excel	2002-2003
165	Fish Abundance for Port Monmouth, Union Beach, Keansburg, Point Comfort, NJ	Excel	2002-2003
166	Fish Sizes Port Monmouth, Union Beach, Keansburg, Point Comfort, NJ	Excel	2002-2003
167	Water Quality for Port Monmouth, Union Beach, Keansburg, Point Comfort, NJ	Excel	2002-2003

168	Jamaica Bay, New York, Salt Marshes	Vector	2000+
169	Historic Jamaica Bay Salt Marsh data, New York	Vector	1924 - 2003
170	Chesapeake Bay Waterbodies, MD, shows wetlands	Vector	Unknown
171	Wetlands (NWI Dataset) in vicinity of GEWA	Vector	1979-2003
172	A Study of Marine Recreational Fisheries in Connecticut	Report	2005-2006
173	Invasive Plant Survey for SAIR	Report	2003
174	Vegetation Classification within SAIR	Report	2003
176	Shellfish Growing Area Classification with closures at ACAD	Vector	1969 - 1993
177	ASIS Park Boundaries	Vector	1972-2005
178	Maryland Coastal Bays Sensitive Areas Initiative geodatabase	Vector	2002
179	Maryland Coastal Bays Sensitive Areas Initiative Technical Report	Report	2004
180	Examining the Effects of a Potential Wind Turbine Facility on the Viewshed of the Assateague Island National Seashore	Report	2007
181	Massachusetts Areas of Critical Environmental Concern	Vector	2003
182	Marine Beaches in Massachusetts	Vector	2003
183	Massachusetts Outstanding Resource Waters	Vector	2002
184	Massachusetts Lobster Harvesting Areas	Vector	1997
185	NJDEP Shellfish Classification 2005 for New Jersey	Vector	2005
186	NJDEP Coastal Planning Areas, New Jersey	Vector	2005
187	Air Quality Monitoring at ASIS	Report	
188	Industrial Discharges and Intakes near COLO	Vector	1994
189	Remediation Sites in New York State	Vector	2006
190	New York State Pollution Discharge Elimination System Program points	Vector	2006
191	National Coastal Assessment Data, Northeast Region	Vector	2000-2002
192	National Coastal Assessment Data, Northeast Region	Vector	2002-2006
193	Assessment of the Ecological Condition of the Delaware and Maryland Coastal Bays	Report	1993
194	EPA EMAP, Virginian Province – Cape Cod, MA to Cape Henry, VA	Vector	1990-1993
195	EPA's Mid-Atlantic Integrated Assessment (MAIA; Delaware Bay to NC coastal sounds)	Vector	1997-1998
196	National Coastal Assessment Data, Southeast Region	Vector	2000-2002
197	EPA STORET Data for Long Island Sound, New York/New Jersey	Vector	1965 to 1989
198	EPA STORET Data for NY/NJ Metro Area	Vector	1965 to 1989
199	Regional EMAP Database 1998-1999 NY/NJ Harbor	Vector	1998 to 1999
200	Regional EMAP Database 1993-1994 NY/NJ Harbor	Vector	1993 to 1994
201	NPS NER Vital Signs Monitoring Hexagons and Random Sampling Points	Vector	2006
202	Location of shipwreck, Exposed and Found in April 1999 within ASIS	Vector	1999
204	Hydrologic framework of Long Island, New York	Report	1989
205	Ground-water resource evaluation on Long Island, New York, using flow models and a geographic information system	Report	1997
206	Simulation of the effects of development of the ground-water flow system of Long Island, New York	Report	1999

207	Simulation of ground-water flow and pumpage in Kings and Queens counties, Long Island, New York	Report	1999
208	Nitrogen concentration and loads in surface- and ground water entering the South Shore Estuary Reserve, Nassau and Suffolk counties, Long Island, New York, 1952-97	Report	1971-1997
209	Geological Interpretation of Bathymetric and Backscatter Imagery of the Sea Floor Off Eastern Cape Cod, Massachusetts	Vector	1998
210	Bathymetric mapping near Watch Hill and Long Cove, Great South Bay, NY	Report	2006
211	Geological Interpretation of Bathymetric and Backscatter Imagery of the Sea Floor Off Eastern Cape Cod, Massachusetts	Vector	1998
214	VA DEQ 2008 305(b)/303(d) Water Quality Assessment Integrated Report – Water quality, pathogens	Report	2001-2006
215	VA DEQ 2008 305(b)/303(d) Water Quality Assessment Integrated Report – Sediment contaminant inventory	Report	2001-2006
216	The Seafloor Revealed: The Geology of the Northwestern Gulf of Maine Inner Continental Shelf	Report	2005
217	Geomorphology and sedimentary framework of Blue Hill and Frenchman Bays and adjacent inner continental shelf: Maine Geological Survey	Report	1991
218	Surficial geology of the Maine inner continental shelf: Rockland to Bar Harbor	Report	
219	Surficial geology of the Maine inner continental shelf: Mt. Desert Island to Jonesport, Maine	Report	1996
220	Bathy30 – bathymetry of Gulf of Maine	Raster	2004
221	bathym100 – bathymetry of Gulf of Maine, 1:100,000, in 10-m intervals	Raster	1999
222	Bathymetry of the Gulf of Maine – seafloor topography	Vector	1999
223	Bedrock geology units and major faults for Maine	Vector	1985-1994
224	Coastal Marine Geologic Environments for Maine	Vector	
225	Water Quality and Ecology of Great South Bay	Report	2005
226	Conservation and Management of the Living Marine Resources of Fire Island National Seashore	Report	2005
228	High-Resolution Geologic Mapping of the Inner Continental Shelf: Boston Harbor and Approaches, Massachusetts	Raster	2000 & 2001
230	Geophysical and Sampling Data from the Inner Continental Shelf: Northern Cape Cod Bay, Massachusetts	Raster	2006-2008
231	Geological Interpretation of Bathymetric and Backscatter Imagery of the Sea Floor Off Eastern Cape Cod, Massachusetts		1998
232	High-Resolution Geologic Mapping of the Inner Continental Shelf: Boston Harbor	Raster	2000 & 2001
233	Geological Interpretation of Bathymetric and Backscatter Imagery of the Sea Floor Off Eastern Cape Cod, Massachusetts	Raster	1998 (acoustic) & 2004 (groundtruth)

234	National Ocean Service's (NOS) Estuarine Bathymetry for 70 US estuaries	Raster	best available in 1998
235	Great South Bay Project – bathymetry of Great South Bay	Raster	multibeam data since 2001
236	Bathymetry in fathoms for Massachusetts and adjacent coastal waters (as polygons)	Vector	published 2008; based on various surveys and survey dates
237	Assessment of shallow-water habitat mapping tools and methods: a pilot study at Fire Island National Seashore	Report	
238	Mapping Nearshore Bathymetry Along the Coast of Fire Island National Seashore	Raster	2008-2010
239	EAARL Topography - Assateague Island National Seashore	Raster	2004
240	Interpolated Grid of VA Coastal Bays Bathymetry, Surveyed in 2007: File Geodatabase Raster Dataset	Raster	July & Aug 2007 (survey dates)
241	High-resolution bathymetric and backscatter mapping in Gateway National Recreation Area – bathymetry and acoustic seabed classification	Report	2008 (survey date)
242	High-resolution bathymetric and backscatter mapping in Gateway National Recreation Area – sediment grain-size	Report	2008
243	Kingman-Mills REMUS survey, Sandy Hook, Gateway National Recreation Area	Raster	2008
244	Bottom Characteristics at Kingman-Mills Sandy Hook, Gateway National Recreation Area	Raster	2008
245	REMUS survey at Kingman-Mills Sandy Hook, Gateway National Recreation Area		2008
246	High-resolution bathymetric and backscatter mapping in Gateway National Recreation Area		2008
247	MD/VA Coastal Bays Bathymetry Map	Report	2010
248	Maryland/Virginia Coastal Bays Sediment 2010 – sediment grain-size	PDF	2010
249	Maryland/Virginia Coastal Bays Sediment 2010 – sediment contaminants	PDF	2010
250	ASIS 1933-1934 File Geodatabase Raster Dataset - bathymetry	Raster	1933-34
251	Bathymetry dataset for the Atlantic Coast of Assateague Island, MD and VA, 1977-1979	Raster	1977-1979
252	Bathymetry of Ocean City, MD 1978	Raster	1978

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